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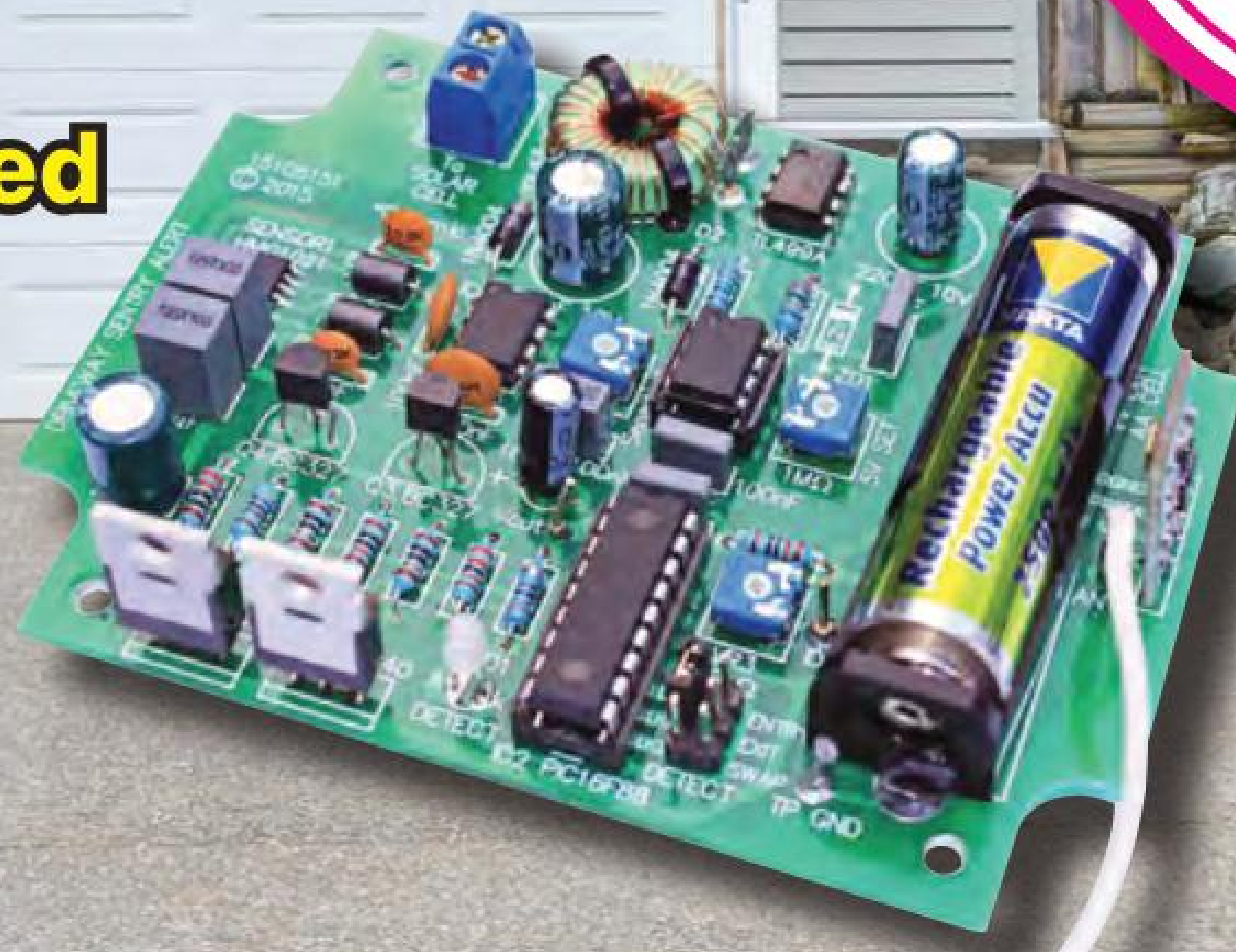

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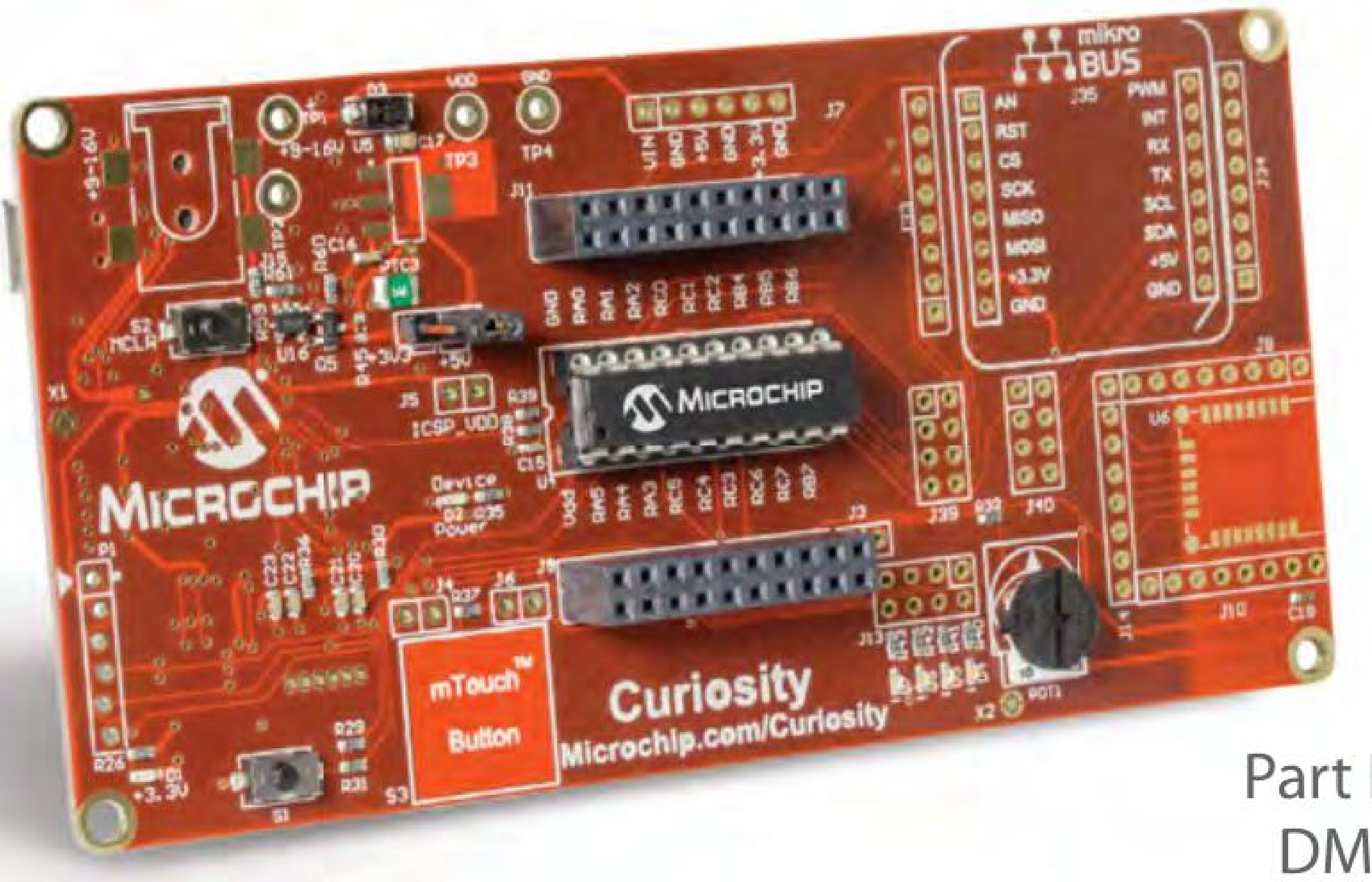
Curiosity Development Board



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Overview:

The Curiosity Development Board is a cost-effective, fully integrated 8-bit development platform targeted at first-time users, makers and those seeking a feature-rich, rapid prototyping board. Designed from the ground-up to take full advantage of Microchip's MPLAB® X integrated development environment, the Curiosity Development Board includes an integrated programmer/debugger, and requires no additional hardware to get started. The Curiosity Development Board supports all low-voltage, programming-enabled 8-bit PIC® MCUs from 8 to 20 pins.

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- Various user interface options
- Full compatibility with MPLAB® X IDE and XC8 compiler

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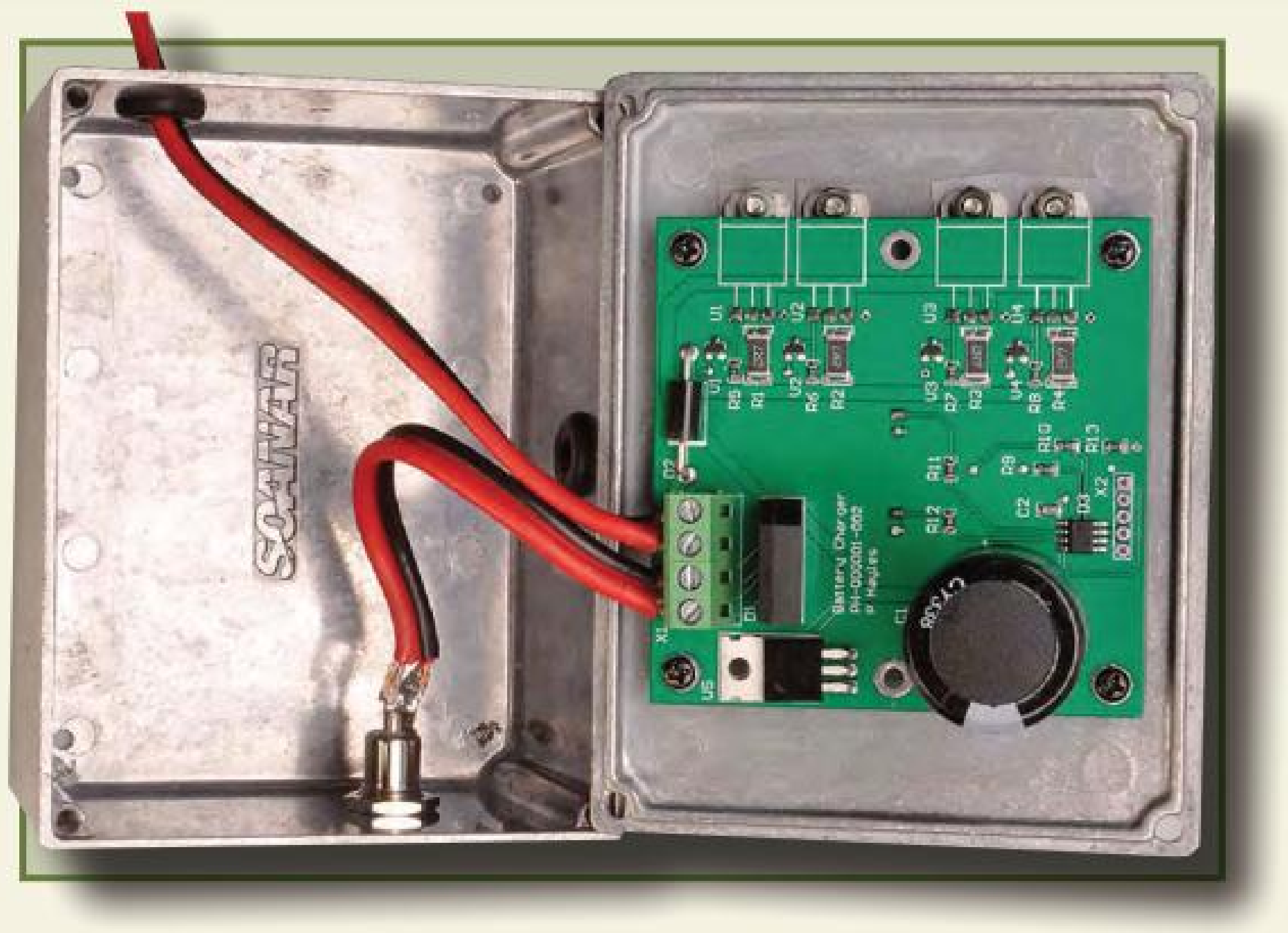

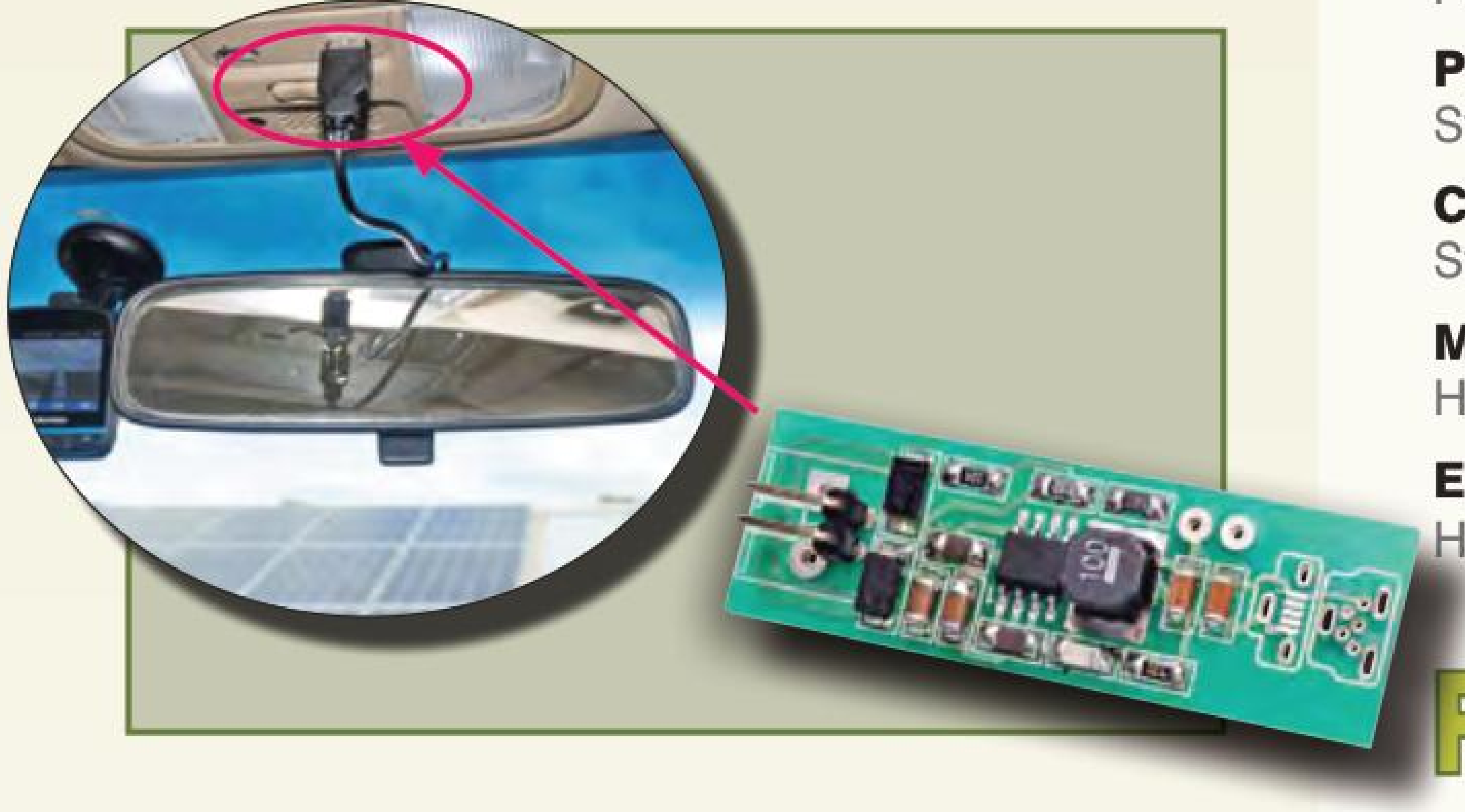

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Exploring the Arduino
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USB or Serial connection. Header cable for ICSP. Free Windows software. See website for PICs supported. ZIF Socket & USB lead extra. 16-18Vdc.
*Kit Order Code: 3149EKT - **~~£49.96~~ £23.95***
*Assembled Order Code: AS3149E - **£38.95***
*Assembled with ZIF socket Order Code: AS3149EZIF - **~~£74.96~~ £48.95***

USB PIC Programmer and Tutor Board

This tutorial project board is all you need to take your first steps into Microchip PIC programming using a PIC16F882 (included). Later you can use it for more advanced programming. It programs all the devices a Microchip PICKIT2® can! You can use the free Microchip tools for the PICKit2™ and the MPLAB® IDE environment.
*Order Code: EDU10 - **£46.74***

ATMEL 89xxxx Programmer

Uses serial port and any standard terminal comms program. 4 LED's display the status. ZIF sockets not included. 16Vdc.
*Kit Order Code: 3123KT - **~~£32.95~~ £21.95***
*Assembled ZIF: AS3123ZIF- **~~£48.96~~ £37.96***

Introduction to PIC Programming

Go from complete beginner to burning a PIC and writing code in no time! Includes 49 page step-by-step PDF Tutorial Manual + Programming Hardware (with LED test section) + Windows Software (Program, Read, Verify & Erase) + a rewritable PIC16F84A. 4 detailed examples provided for you to learn from. PC parallel port. 12Vdc.
*Kit Order Code: 3081KT - **£17.95***
*Assembled Order Code: AS3081 - **£24.95***

PICKit™2 USB PIC Programmer Module

Versatile, low cost, PICKit™2 Development Programmer. Programs all the devices a Microchip PICKIT2 programmer can. Onboard sockets & ICSP header.
*Assembled Order Code: VM203 - **£39.54***

PIC Programmer & Experimenter Board

PIC Programmer & Experimenter Board with test buttons and LED indicators to carry out educational experiments such as the supplied programming examples. Includes a 16F627 Flash Microcontroller that can be reprogrammed up to 1000 times. Software to compile and program your source code is included. Supply: 12-15Vdc.
*Kit Order Code: K8048 - **~~£29.58~~ £21.54***
*Assembled Order Code: VM111 - **£38.88***

Controllers & Loggers

Here are just a few of the controller and data acquisition and control units we have. See website for full details. 12Vdc PSU for all units: Order Code 660.446UK £10.68

USB Experiment Interface Board

Updated Version! 5 digital inputs, 8 digital outputs plus two analogue inputs and two analogue outputs. 8 bit resolution. DLL.
*Kit Order Code: K8055N - **~~£39.95~~ £22.74***
*Assembled Order Code: VM110N - **£39.95***

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State-of-the-art high security. Momentary or latching relay outputs rated to switch up to 240Vac @ 10 Amps. Range up to 40m. 15 Tx's can be learnt by one Rx (kit includes one Tx but more available separately). Supply 9-15Vdc.
*Kit Order Code: 8157KT - **£44.95***
*Assembled Order Code: AS8157 - **£49.96***

Computer Temperature Data Logger

Serial port 4-channel temperature logger. °C or °F. Continuously logs up to 4 separate sensors located 200m+ from board. Wide range of free software applications for storing/using data. PCB just 45x45mm. Powered by PC. Includes one DS1820 sensor.
*Kit Order Code: 3145KT - **~~£19.95~~ £16.97***
*Assembled Order Code: AS3145 - **£22.97***
*Additional DS1820 Sensors - **£4.96 each***

8-Channel Ethernet Relay Card Module

Connect to your router with standard network cable. Operate the 8 relays or check the status of input from anywhere in world. Use almost any internet browser, even mobile devices. Email status reports, programmable timers, ...
*Assembled Order Code: VM201 - **£134.40***

Many items are available in kit form (KT suffix) or pre-assembled and ready for use (AS prefix)

4-Ch DTMF Telephone Relay Switcher

Call your phone number using a DTMF phone from anywhere in the world and remotely turn on/off any of the 4 relays as desired. User settable Security Password, Anti-Tamper, Rings to Answer, Auto Hang-up and Lockout. Includes plastic case. 130 x 110 x 30mm. Power: 12Vdc.
*Kit Order Code: 3140KT - **£79.95***
*Assembled Order Code: AS3140 - **£94.95***

8-Ch Serial Port Isolated I/O Relay Module

Computer controlled 8 channel relay board. 5A mains rated relay outputs and 4 opto-isolated digital inputs (for monitoring switch states, etc). Useful in a variety of control and sensing applications. Programmed via serial port (use our new Windows interface, terminal emulator or batch files). Serial cable can be up to 35m long. Includes plastic case 130x100x30mm. Power: 12Vdc/500mA.
*Kit Order Code: 3108KT - **£74.95***
*Assembled Order Code: AS3108 - **£89.95***

Infrared RC 12–Channel Relay Board

Control 12 onboard relays with included infrared remote control unit. Toggle or momentary. 15m+ range. 112 x 122mm. Supply: 12Vdc/0.5A
*Kit Order Code: 3142KT - **~~£64.96~~ £51.96***
*Assembled Order Code: AS3142 - **£61.96***

Audio DTMF Decoder and Display

Detect DTMF tones from telephone handsets, tape recorders, receivers, two-way radios, etc using the built-in mic *or* direct from the phone line. Characters are displayed on a 16 character display as they are received and up to 32 numbers can be displayed by scrolling the display. All data written to the LCD is also sent to a serial output for connection to a computer. Supply: 9-12V DC. Main PCB: 55x95mm.
*Kit Order Code: 3153KT - **£37.96***
*Assembled Order Code: AS3153 - **£49.96***

3x5Amp RGB LED Controller with RS232

3 independent high power channels. Preprogrammed or user-editable light sequences. Standalone option and 2-wire serial interface for microcontroller or PC communication with simple command set. Suitable for common anode RGB LED strips, LEDs and incandescent bulbs. 56 x 39 x 20mm. 12A total max. Supply: 12Vdc.
*Kit Order Code: 8191KT - **~~£29.95~~ £24.95***
*Assembled Order Code: AS8191 - **£29.95***

Hot New Products!

Here are a few of the most recent products added to our range. See website or join our email Newsletter for all the latest news.

4-Channel Serial Port Temperature Monitor & Controller Relay Board

4 channel computer serial port temperature monitor and relay controller. Four inputs for Dallas DS18S20 or DS18B20 digital thermometer sensors (£3.95 each). Four 5A rated relay outputs are independent of sensor channels allowing flexibility to setup the linkage in any way you choose. Simple text string commands for reading temperature and relay control via RS232 using a comms program like Windows HyperTerminal or our free Windows application.
Kit Order Code: 3190KT - ~~£84.95~~ **£59.95**
Assembled Order Code: AS3190 - **£74.95**

40 Second Message Recorder

Feature packed non-volatile 40 second multi-message sound recorder module using a high quality Winbond sound recorder IC. Standalone operation using just six onboard buttons or use onboard SPI interface. Record using built-in microphone or external line in. 8-24Vdc powered. Change a resistor for different recording duration/sound quality. Sampling frequency 4-12 kHz. (120 second version also available)
Kit Order Code: 3188KT - ~~£29.95~~ **£23.96**
Assembled Order Code: AS3188 - **£31.97**

Bipolar Stepper Motor Chopper Driver

Get better performance from your stepper motors with this dual full bridge motor driver based on SGS Thompson chips L297 & L298. Motor current for each phase set using on-board potentiometer. Rated to handle motor winding currents up to 2 Amps per phase. Operates on 9-36Vdc supply voltage. Provides all basic motor controls including full or half stepping of bipolar steppers and direction control. Allows multiple driver synchronisation. Perfect for desktop CNC applications.
*Kit Order Code: 3187KT - **£39.95***
*Assembled Order Code: AS3187 - **£49.96***

LCD Oscilloscope Kit

Build your own oscilloscope with LCD display. Learn how to read signals with this exciting new kit. See the electronic signals you learn about displayed on your own LCD oscilloscope. Despite the low cost, this oscilloscope has many features found on expensive units, like signal markers, frequency, dB, true RMS readouts and more...
*Kit Order Code: EDU08 - **£49.99***

Motor Speed Controllers

Here are just a few of our controller and driver modules for AC, DC, Unipolar/Bipolar stepper motors and servo motors. See website for full details.

DC Motor Speed Controller (100V/7.5A)

Control the speed of almost any common DC motor rated up to 100V/7.5A. Pulse width modulation output for maximum motor torque at all speeds. Supply: 5-15Vdc. Box supplied. Dimensions (mm): 60Wx100Lx60H.
*Kit Order Code: 3067KT - **£19.95***
*Assembled Order Code: AS3067 - **£27.95***

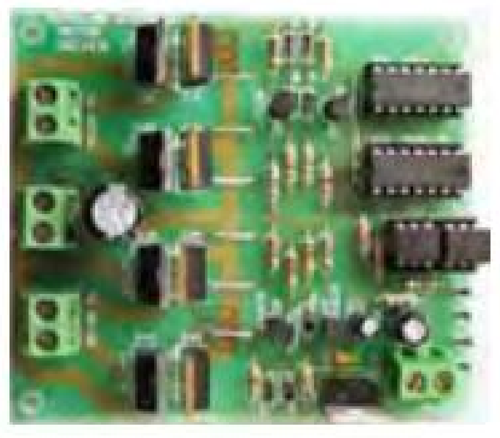
Bidirectional DC Motor Speed Controller

Control the speed of most common DC motors (rated up to 32Vdc/10A) in both the forward and reverse direction. The range of control is from fully OFF to fully ON in both directions. The direction and speed are controlled using a single potentiometer. Screw terminal block for connections.
*Kit Order Code: 3166v2KT - **£23.95***
*Assembled Order Code: AS3166v2 - **£33.95***

Computer Controlled / Standalone Unipolar Stepper Motor Driver

Drives any 5-35Vdc 5, 6 or 8-lead unipolar stepper motor rated up to 6 Amps. Provides speed and direction control. Operates in stand-alone or PC-controlled mode for CNC use. Connect up to six 3179 driver boards to a single parallel port. Board supply: 9Vdc. PCB: 80x50mm.
*Kit Order Code: 3179KT - **£17.95***
*Assembled Order Code: AS3179 - **£24.95***

Computer Controlled Bi-Polar Stepper Motor Driver



Drive any 5-50Vdc, 5 Amp bi-polar stepper motor using externally supplied 5V levels for STEP and DIRECTION control. Opto-isolated inputs make it ideal for CNC applications using a PC running suitable software. Board supply: 8-30Vdc. PCB: 75x85mm.
*Kit Order Code: 3158KT - ~~£24.95~~ **£21.20***
*Assembled Order Code: AS3158 - **£31.20***

AC Motor Speed Controller (600W)

Reliable and simple to install project that allows you to adjust the speed of an electric drill or 230V AC single phase induction motor rated up to 600 Watts. Simply turn the potentiometer to adjust the motors RPM. PCB: 48x65mm. Not suitable for use with brushless AC motors.
*Kit Order Code: 1074KT - ~~£15.95~~ **£13.56***
*Assembled Order Code: AS1074 - **£21.56***

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Designed by electronics enthusiasts for electronics enthusiasts! Powerful, compact and USB connectivity, this sums up the features of this oscilloscope. 40 MHz sampling rate, 12 MHz analogue bandwidth, 0.1 mV sensitivity, 5mV to 20V/div in 12 steps, 50ns to 1 hour/div time base in 34 steps, ultra fast full auto set up option, adjustable trigger level, X and Y position signal shift, DVM readout and more...
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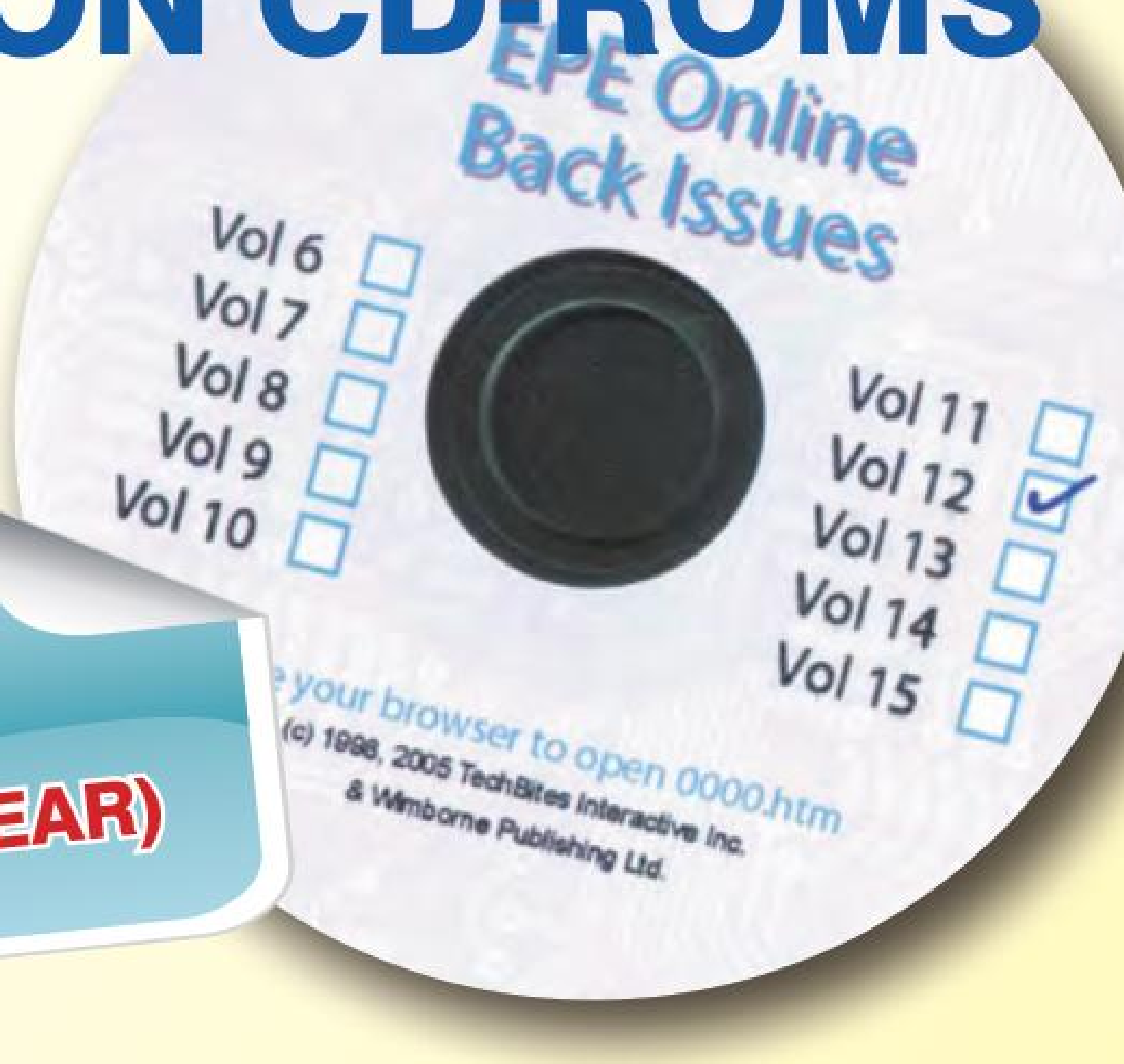
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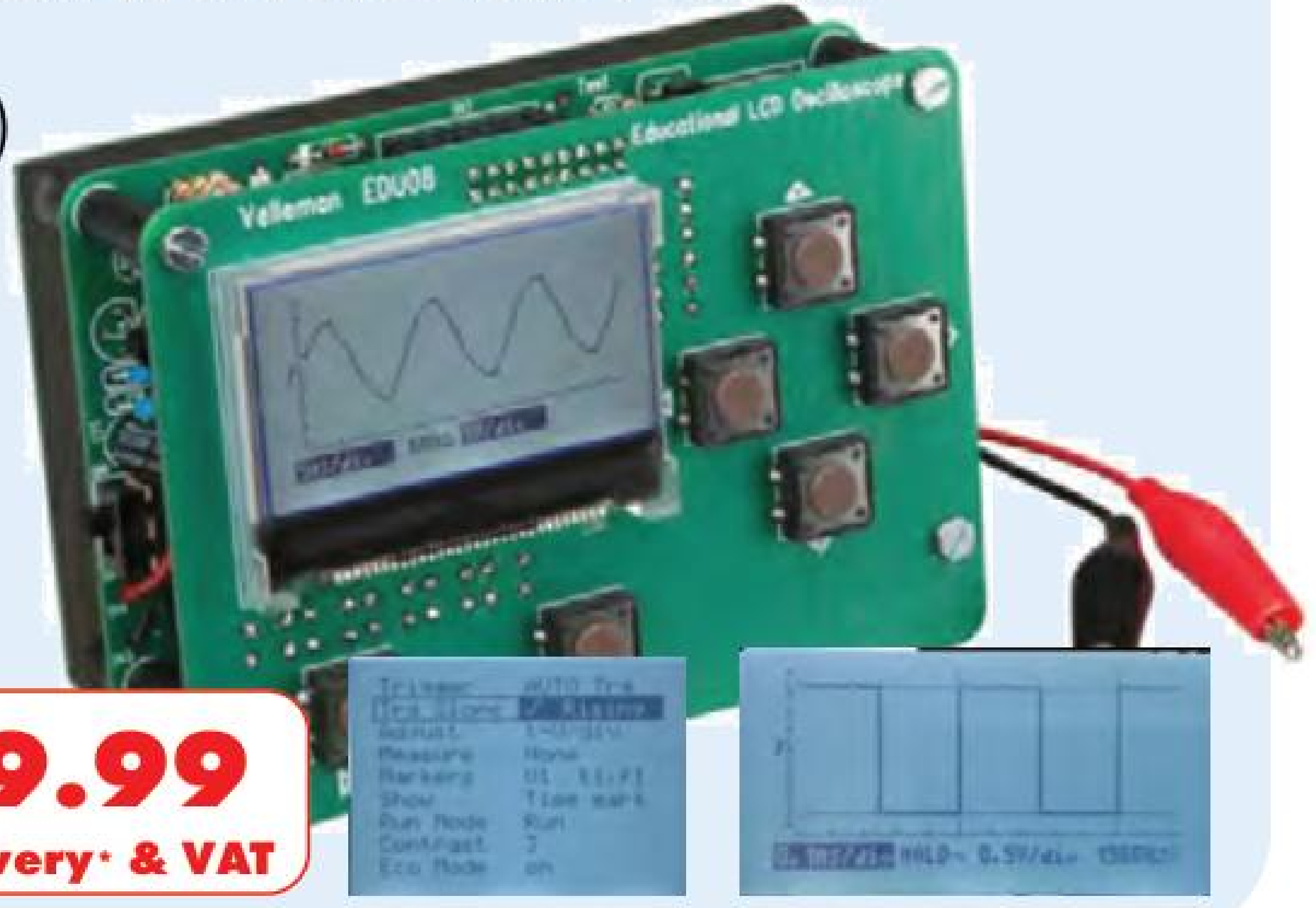

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VOL. 45 No. 07 JULY 2016

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EDITORIAL Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset, BH21 1UU
Phone: 01202 880299. **Fax:** 01202 843233.
Email: fay.kearn@wimborne.co.uk
Website: www.epemag.com
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General Manager:	FAY KEARN
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EPE EVERYDAY PRACTICAL ELECTRONICS

Much more than 'just a map'

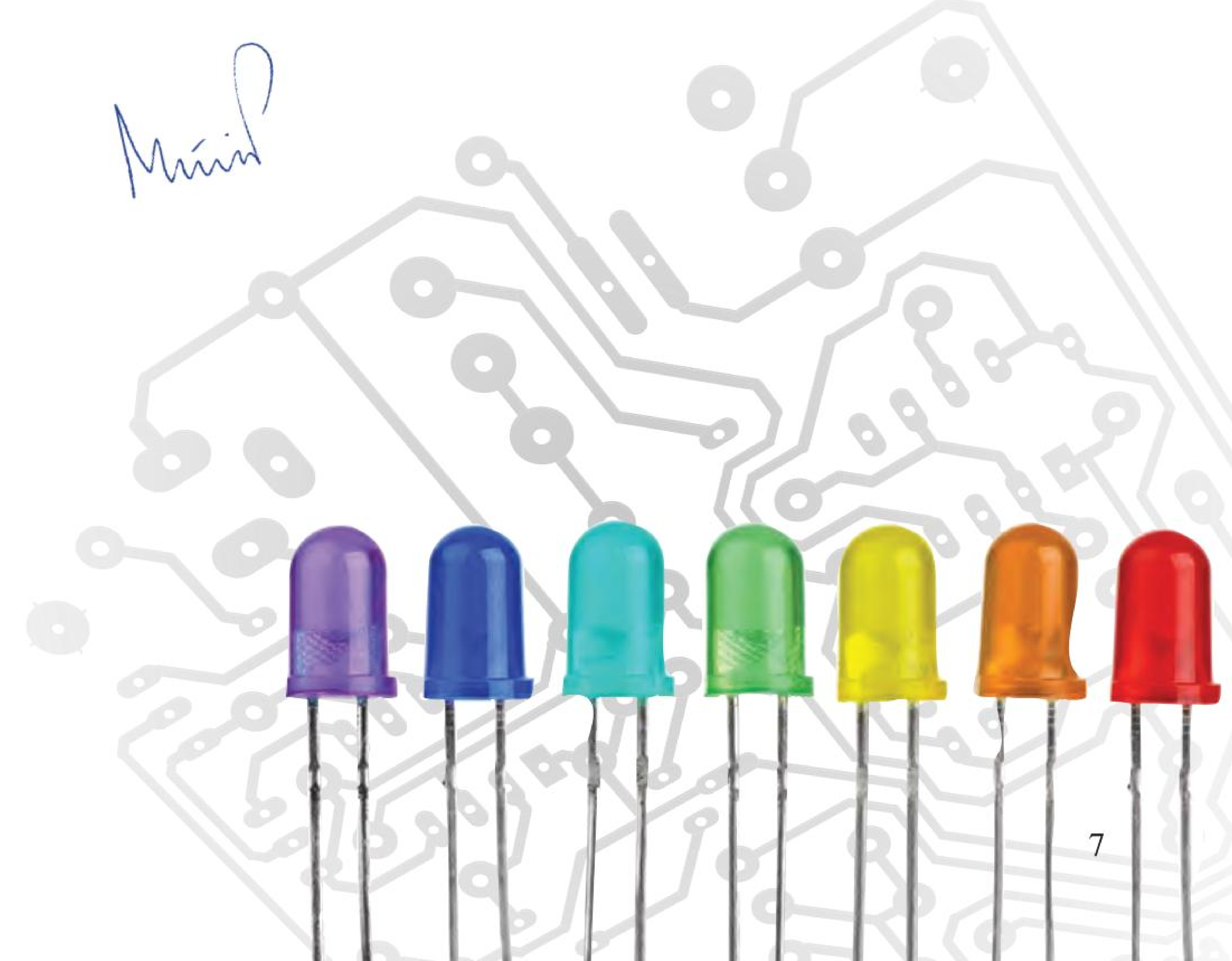
I always enjoy Alan Winstanley's wide-ranging review of PCs and the online world in *Net Work*. His look at VR last month and in this issue shows just how much can be achieved with a bit of cardboard… and a smartphone. However, what really caught my eye this month was his description of the many uses people find for Google Maps, something I have increasingly appreciated over the last few months. My wife recently started work as a domestic care worker, which involves a lot of travel in and around the centre of Brighton. For each day, the times and locations of her allotted visits are emailed the night before and it falls to me to plot her routes using – of course – Google Maps. What I hadn't realised was just how much public transport data Google has managed to hoover up. The times and schedules of every bus on every route are available, so you can plot and plan to a very high degree of precision the best way to travel. I can only assume that Google works very hard with bus (and train) providers to keep the data up to date. The service is free, accurate and has been a real lifesaver. Attempting to do this with just a book of timetables simply doesn't bear thinking about.

Arduino World goes wireless

We're roughly half way through Mike and Richard Tooley's excellent *Teach-In 2016*, and have reached one of the sections I've most looked forward to reading – developing wireless systems around the Arduino. I hope you enjoy reading it and are inspired to develop your own cable-free projects and systems using the ideas that are explained this month.

I'm really pleased with the way this year's *Teach-In* series has progressed. My brief to Mike and Richard was simple – we don't want to treat Arduino as a complex standalone 'component' – PIC projects and Mike O'Keeffe's excellent *PIC 'n Mix* column have that topic well covered. What I wanted – and they have delivered – is a sophisticated 'Lego approach' that gives you easy-to-use building blocks to quickly prototype and construct exciting projects.

Of course, there's much else in this issue – from great projects to must-read columns… so welcome to, and please have fun with July's *EPE*!



NEWS

A roundup of the latest Everyday News from the world of electronics

Visiting a Chinese electronics exhibition – report *by Barry Fox*

The IFA Consumer Electronics show held in Berlin every September rivals the January CES in Las Vegas. (IFA stands for *Internationale Funkausstellung Berlin*, or the 'International radio exhibition Berlin', a testament to the vintage of this important event.) CES has now spun off into China with CES Asia in Shanghai, so it was entirely predictable that IFA would move into China. IFA's first China show was held in Shenzhen in April, and IFA invited nearly 400 journalists from around the world to witness the opening.

An invitation is not a visa

Shenzhen is an industrial zone and skyscraper city just across the border from comparatively liberal Hong Kong, and the border crossing reminds one of Checkpoint Charlie when East and West Berlin were separated by the Wall. IFA's Berlin team flew the press into Hong Kong for a pre-show briefing and then bussed us to Shenzhen. But, foreigners need visas or entry permits, and Mainland China is paranoid over visiting press.

European Hi-Fi manufacturer iFi Audio was a popular destination for Chinese visitors

Although the official show literature proclaimed, 'Shenzhen welcomes the global CE industry at first ever CE China event... a city and region opening its arms to the world', the Hong Kong pre-show event buzzed with horror stories about the difficulties of getting visas. Three UK journalists had dropped out of the entire trip after three fruitless interview visits to the London Visa office where Chinese officials nit-picked forms. One Brit beat the system only by 'photoshopping' a crucial document to correct a minor but fatal error; another applied by post for a tourist visa from China's office in Scotland.

I applied for a visa online, and was given an official reference number, but never heard anything further. In the event, I crossed the border with only my passport, which does not identify me as a journalist, by getting a temporary business entry permit for Shenzhen only. This was issued on-the-spot in return for cash paid over a grimy counter in what looked like a cow shed.

VR GLASSES
VR虚拟现实智能眼镜
给我一个世界
Open A New World

Virtual Reality in Shenzen, but no demo of the Glass V1

Early days

Was it worth it? For the experience, Yes. For the show, No. But to be fair, the IFA Organisers had said upfront in Hong Kong that their first attempt – called CE China rather than IFA China – was 'just a toe in the water'.

'We will see where the journey goes and where the path leads us' said Dr Christian Goke, CEO Messe Berlin, the IFA organisers. '... it would have been presumptuous and misleading to call the show IFA China. It is not the big international CE market place and it does not pretend to be that. It is the international Chinese brand show, with 150 exhibitors.'

CE China was held at the new Sheena Convention and Exhibition Centre in the main square of Shenzhen city. Entry was free to accredited trade and although no hard numbers have yet been released, the first afternoon saw attendance swell to healthy but not oppressive numbers.

Information in English was seldom available, which is, of course, to be expected for a Chinese Mainland show. Major names familiar in the West, such as Siemens, Karcher and

Visiting a Chinese electronics exhibition *continued*

Bosch showed mainly home appliances, while local big name Soning offered Smart Home technology, Amazon promoted Global Selling and LeTV offered a wide range of large screen HD and 4K TVs.

Round the sides of the main floor area, neat alleys of small booths showed the usual wide variety of CE accessories and domestic appliances, ranging from rice cookers and pre-programmed electronic musical instruments to earbuds and wired and wireless speakers and headphones.

Bluetooth overload and VR

There were so many Bluetooth headsets being demonstrated in the hall with so many smartphones, Aska Electronics explained when their music demo broke up, that connection was unavoidably unreliable.

Vargo was showing a smartphone, which is claimed to offer end-to-end security. It remains to be seen how the Chinese authorities handle this.

Press who had been present at IFA's seminars at a hotel in Shenzhen the day before the show made a beeline for the Dlodlo booth, hoping for a working demonstration of the Glass V1 Virtual Reality glasses which the company had promised will 'redefine the Virtual Reality...and your mobile digital life' because they look like sunglasses, are only 16mm thick and weigh only 78 g, so 'can be put in your pocket'.

This appealing idea was on display at the show, but under glass and not working. Working VR demonstrations were given by Dlodlo with bulky phone-carrying headsets. There was no information on when the V1 pocket glasses will be available to buy and at what cost.

I spotted a few Hi-Fi exhibits, including Onkyo AV receivers and headphones, and an impressive-sounding lab prototype pair of headphones from audio earbud specialist Ostry. The booth for European Hi-Fi company iFi Audio was continually busy, with small crowds curious about its 'Clean Power' units, desktop and tube amplifiers, and a HiRes DSD DAC.

The great Firewall of China

Although the show-ground offered free Wi-Fi for visitors, connection to some sites, notably Twitter, Facebook, YouTube and Google – and now Apple iTunes – is officially blocked throughout China. AOL, Bing, and Yahoo usually worked, albeit erratically, along with China's approved search engine **baidu.com**.

Instead of the usual private Press Room, CE China provided only a few tables in an open area of the show, labelled 'Media Workspace' and continually patrolled by menacing security police who ostentatiously looked at journalists' laptop screens – even though it is highly unlikely they could read what was being written.

The news very soon spread that despite this police presence, valuables such as phones and cameras were being stolen from the tables unless owners physically tied them down.

A couple of Brits who got bored with the event ventured into downtown Shenzhen and boggled at the huge variety of raw electronic components on sale in the shops. You could build anything off the shelf, they reckoned.

VERY long-lasting battery

Yes, another battery story! It may seem that almost every other month someone somewhere invents a new way to store electricity, but this is very much a reflection of the sheer scale of battery research worldwide. Driven by the search for the 'ideal' battery for electric cars, mobile electronics and a whole host of other applications, the market and demand for improvements – both incremental and truly disruptive – is vast.

Batteries have to balance a difficult set of requirements – high power density, fast recharge, long life, cheap, safe and reliable. Of these, the power density and fast recharge properties tend to hog the limelight, but the ability to be charged/discharged/recharged many times is often overlooked. Now, researchers at the University of California Irvine have found a way to make a battery that can be reliably recharged 200,000 times without significant degradation. The new technology uses gold nanowires coated with manganese oxide and protected with an electrolyte gel. The researchers admit they are not sure exactly why their new process exhibits such extreme longevity, but they are planning to build batteries using this novel technology and discover how it works.

On and on and on... new battery technology offers 200,000 charge/discharge cycles

New models from PicoScope

PicoScope 2000 Series
pico
Technology

New PicoScope 2000 series oscilloscopes now deliver the functionality of six instruments in an ultra-portable package.

PicoScope two-channel, four-channel and mixed-signal models have the functionality of an oscilloscope plus a logic analyser, spectrum analyser, function generator, arbitrary waveform generator, and serial bus analyser with support for 15 protocols included as standard. They are USB-powered and come in an ultra-portable package that can be easily transported in a laptop bag.

PicoScope 6 software, included with the scopes, has been updated with support for touchscreen PCs and tablets.

3D-MID prototype service

PCB and front panel fabricators Beta LAYOUT are offering a new service. Customers can now order prototype quantities of 3D-MIDs (3D mechatronic intergrated devices). Beta's aim is to introduce 3D-MID technology to a wider audience and help reduce the high cost normally associated with MID prototyping.

3D-MIDs are three-dimensional bodies with integrated circuit structures. A metallised thermoplastic part (MID) replaces the circuit board plus additional components, which usually consists of many different materials. The 3D-MIDs are made of recyclable thermoplastics and are easier to dispose of than conventional circuit boards.

BETA avoids the high costs associated with traditional injection molded 3D-MIDs by producing laser sintered prototypes, which are manufacturable at relatively low price.

Further details at: **pcb-pool.com/ppuk/info_pcbpool_3d_mid.html**

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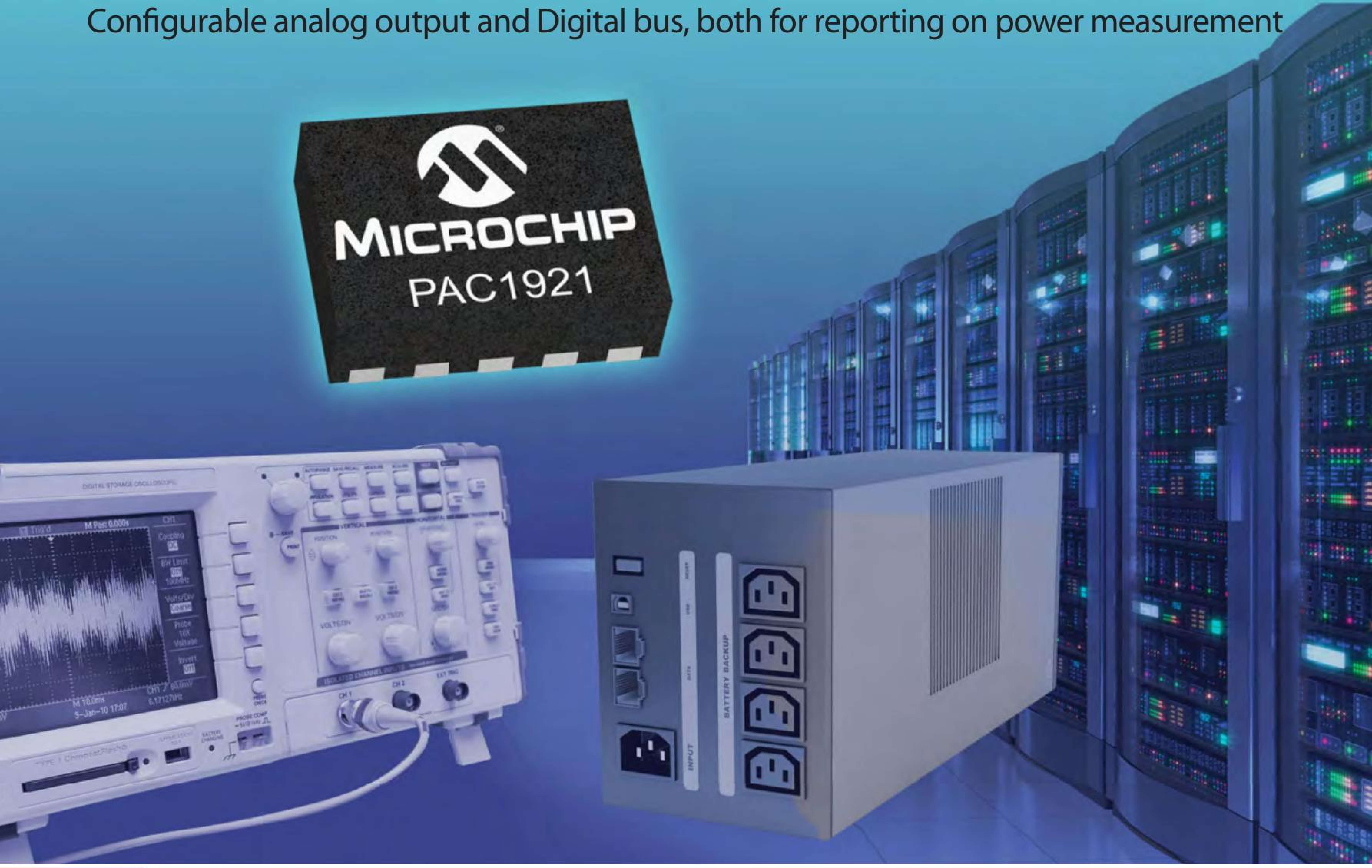
A world first in high-side current sensing

Configurable analog output and Digital bus, both for reporting on power measurement



Microchip's PAC1921 is the world's first high-side current/power sensor to present power, current or voltage over a single output pin.

Using the 2-Wire digital bus to maximise data and diagnostic reporting, and the configurable analog output to minimise data latency, the PAC1921 increases flexibility in high-speed power management applications.

The PAC1921's analog output can be adjusted for 3V, 2V, 1.5V or 1V microcontroller inputs and measure system-load power from 0V to 32V.

- Flexible power measurement and diagnostics
- 39-bit accumulation register
- 128 times current gain configuration
- 32 times voltage gain configuration

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TechnoTalk

Light reading

Mark Nelson

Optical communication is the theme this month. Nothing heavy for certain – but plenty that's novel, even wacky or else shrouded in the mists of time. Mark Nelson enlightens you.

WITH EVER MORE HOMES AND offices connected to the Internet by fibre broadband these days, you might think that everything has been perfected, leaving nothing much left to be invented in the optical communication department. It's true that many elements of photonics (lightwave electronics) are now integrated in chips, but the functionality inside these modules is generally fixed or 'hard-wired'. Think of field-programmable gate arrays and other 'flexible' semiconductor designs; if you could have optical elements that were similarly reconfigurable, this would allow light to be routed flexibly, opening up new applications in programmable photonic circuits.

Patterns of light

As you have probably guessed, researchers have already had this self-same thought. Researchers from the UK's University of Southampton and the Institut d'Optique in Bordeaux, France have devised a new approach for controlling light in a silicon chip by bringing the concept of spatial light modulation to integrated optics. 'Controlling integrated optical circuits using patterns of light' is what they call this technique, which makes use of multimode interference (MMI) devices, which form a versatile class of integrated optical elements routinely used for splitting and recombining different signals on a chip.

This is in contrast to the existing spatial light modulators, which are based on liquid crystals or 'micromirrors' and provide many independently controllable pixels. This technology, which has revolutionised optics in recent years, has many applications in imaging and holography, adaptive optics and wavefront-shaping of light through opaque media. Light travelling through the MMI device can now be controlled dynamically. A pattern of local perturbations (a change in the normal movement of the light), induced by a laser, acts in concert to effectively shape the transmitted light. Related to wavefront-shaping in free-space optics, this allows light to be routed freely within a static silicon element, thus transforming the device into a much-needed building block for field-programmable photonics.

Roman Bruck, a postdoctoral researcher at the University of Southampton, explains that practical applications of this technology will include all-optical reconfigurable routers, ultra-fast optical modulators and switches for optical networks and microwave photonic circuits as well as wafer-scale optical testing of photonic chips. His colleague Prof Otto Muskens sums up: 'There are many new directions to explore, from gaining a deeper understanding to application of the new concepts into real-world devices. This is a potentially disruptive new approach toward field-programmable chips, which can enhance and complement existing strategies, or even partially replace current technology.'

Light relays

It may surprise you to learn that the first research work of this kind took place 90 (yes!) years ago, when the self-taught Russian radio technician Oleg Losev, also written as 'Losov' or 'Lossev' and pronounced 'Olyeg Lossov', invented the 'light relay' concept. Now considered one of the world's first semiconductor physicists, he had previously noticed that some silicon carbide diodes (the crystals used in crystal receivers) found in radios emitted light when current was passed through them. He investigated the subject of electroluminescence in depth, publishing a number of scientific papers discussing the current versus voltage characteristics of SiC diodes and their relation to light emission. One of these, 'Luminous carborundum detector and detection effect and oscillations with crystals', in the British periodical *Philopsophical Magazine* (November 1928) ran to 21 pages.

Losev had no doubts about the practical significance of his work. He realised that these miniature non-vacuum light sources – which operated at low voltages (less than 10V) and at very high speed – could perform tasks that normal light bulbs were unable to, and were a revolutionary concept. His 1927 patent for a 'light relay' foresaw its use 'for fast telegraphic and telephone communication, transmission of images and other applications when a light luminescence contact point is used as the light source connected directly to a circuit of modulated current' – in other words, the optoelectronic systems that make modern communications possible. Tragically, his promising investigations ended in 1942 when he died of starvation in the Siege of Leningrad, aged only 39.

If you feel like discovering more about this pioneering work that took place so long ago, you should read the paper listed below. It's probably no coincidence that it too comes from the University of Southampton: **http://tinyurl.com/befg4bc**

Free teevee

Back in the 1960s there was much talk of 'free radio'– free in the sense of not being controlled by the government. In those days, nations jealously guarded and controlled access to the airwaves for radio and television broadcasting, although a number of so-called pirate radio stations operated from offshore waters. Regulation of the electromagnetic spectrum does not extend beyond 275GHz, however. Spotting that government monopoly control did not cover the optical wavelengths, one would-be broadcaster by the name of Radio Love announced it would establish an optical 'radio' station atop the then-iconic Centre Point tower block in London, and would also arrange to adapt people's transistor portable radios to pick up the lightwave transmissions. You can read more about it and other optical radio experiments at: **http://tinyurl.com/gnpjb4r**

Radio Love never came to fruition, but nearly half a century later an enterprising experimenter is now well on the way to exploiting the same technique – for transmitting television. Steve Ostler is the man behind this research and he has demonstrated how a complete television sound and vision channel can be radiated, encapsulated in light. A simple-to-receive, ready-to-go RF channel emerges from the photo-sensor receptor, enabling it to be connected directly into the antenna socket of a television receiver. He uses near infra-red transmissions, as these are easier to generate and detect than far infra-red or millimetric waves. The constant 'DC' component of daylight does not create a problem, as the receptor developed already works satisfactorily by day or night. Transmission range is very much line-of-sight of course. You can read all the details at: **www.radiocraft.co.uk/opto.htm** and will probably find the rest of his website just as fascinating.

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Driveway Monitor

Part 1 – By JOHN CLARKE

Based on a Honeywell magneto-resistive sensor, this *Driveway Monitor* provides an audible and visual indication when a vehicle is detected. Alternatively, it can be made to activate a remote-controlled mains switch to turn on lights for a preset time.

OUR DRIVEWAY MONITOR will alert you to any vehicle arriving in your driveway and it's equally useful on a farm, detecting vehicles passing through a gate.

Several methods can be used for vehicle detection, including infrared and ultrasonic beam set-ups. However, infrared and ultrasonic beams are prone to false triggering so a typical vehicle detection system relies on the very small changes in the Earth's magnetic field caused by the presence of a vehicle. Fig.1 shows a representation of the distortion in the Earth's magnetic field caused by the presence of a vehicle.

Our previous *Driveway Sentry*, published in August 2013 used a coil of wire to detect changes in the Earth's magnetic field when a vehicle passed over it. This coil could either be laid under the driveway or concealed in the expansion joints, if that was possible. While this arrangement can work well if you are installing a new system, you wouldn't want to jack-hammer an existing concrete driveway to lay a cable under it!

Our new *Driveway Monitor* sidesteps this problem by using a Honeywell magneto-resistive sensor, as used for magnetic field sensing in electronic compasses. It's so sensitive that it doesn't need to be located under the driveway; somewhere alongside the driveway is sufficient.

The magneto-resistive sensor is teamed with a sensitive instrumentation op amp and a PIC microcontroller that outputs a coded 433MHz signal. This is picked up by a companion 433MHz receiver unit with various optional outputs.

Once triggered, the receiver unit flashes a green or red LED and sounds a piezo alarm. It will even tell you which way the vehicle is heading, since a different distinct sound is made by the piezo transducer for each direction, while a third tone indicates vehicle movement in either direction. In addition, the green LED flashes for vehicles entering the driveway, while the red LED flashes for vehicles exiting the driveway.

Alternatively, the LEDs/piezo transducer can be omitted and a couple of reed relays fitted to the receiver PCB instead. These can trigger a UHF remote-controlled mains socket (via its remote), a wireless doorbell remote or even the remote for a motorised gate opener.

The detector circuitry is installed in an IP65 case (115 × 90 × 55mm) that's dust tight and able to withstand wet weather. This would normally be mounted alongside the driveway, either on an adjacent fence, wall or post.

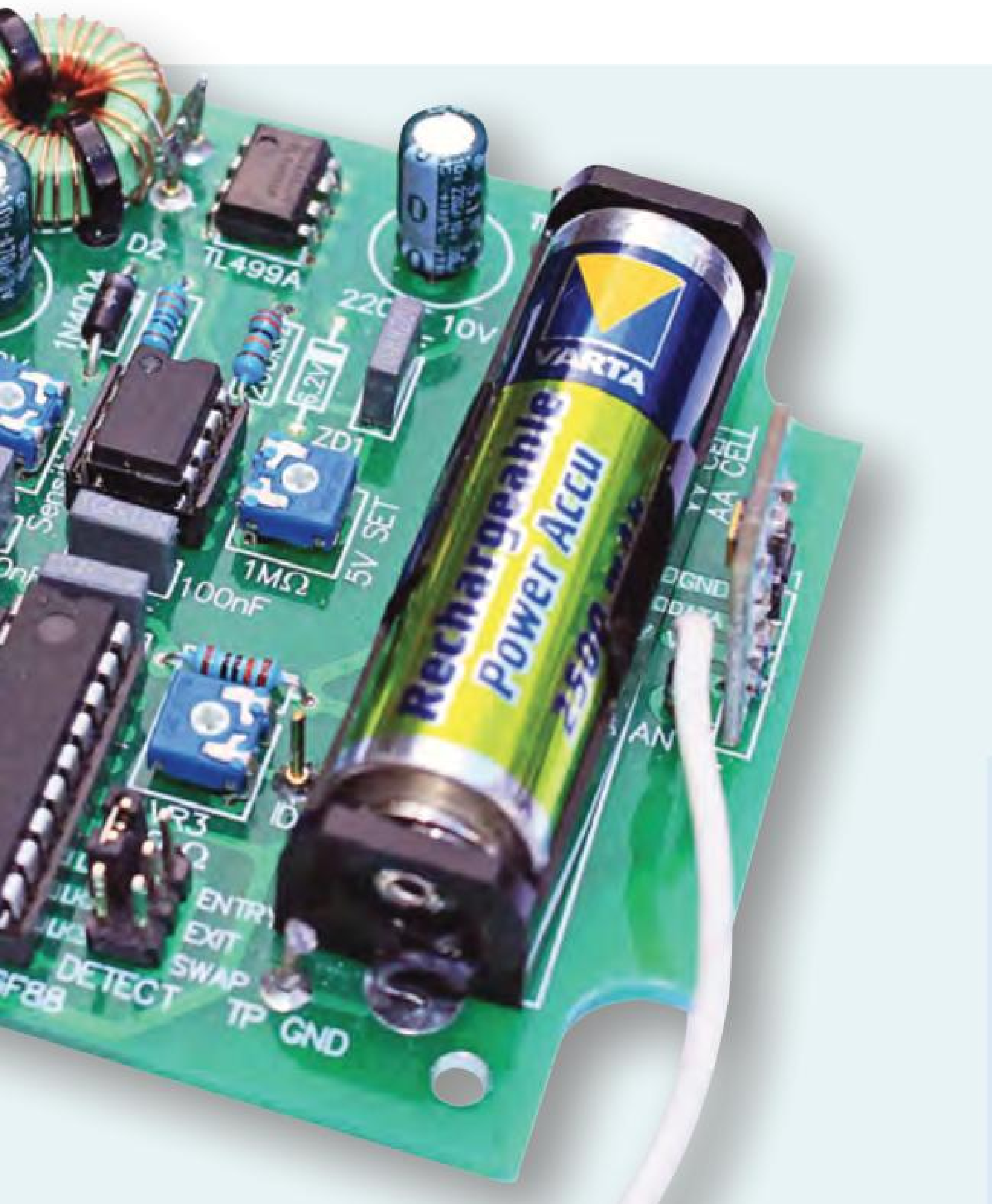
Power for the detector comes from a single 1.25V AA NiMH cell that's recharged using a solar cell panel (the same as those used with solar garden lights). *No mains power is necessary*.

On the other hand, if you don't want to use solar power and there is access to undercover mains power, a small 9-12V DC plugpack could be used to recharge the NiMH cell.

The companion receiver unit is housed in a small plastic case and is powered from a 12V DC plugpack. It can be placed where it can be readily heard and seen, if you intend using it purely as an audible/visual indicator. Alternatively, it can be placed out of sight if you intend using it to trigger a remote-controlled mains socket or some other device.

Block diagram

Fig.2 shows the block diagram of the detector circuit. It's based on the Honeywell HMC1021S one-axis magneto-



The detector PCB carries the magneto-resistive sensor and is mounted in a waterproof case near the driveway (note: prototype PCB shown).

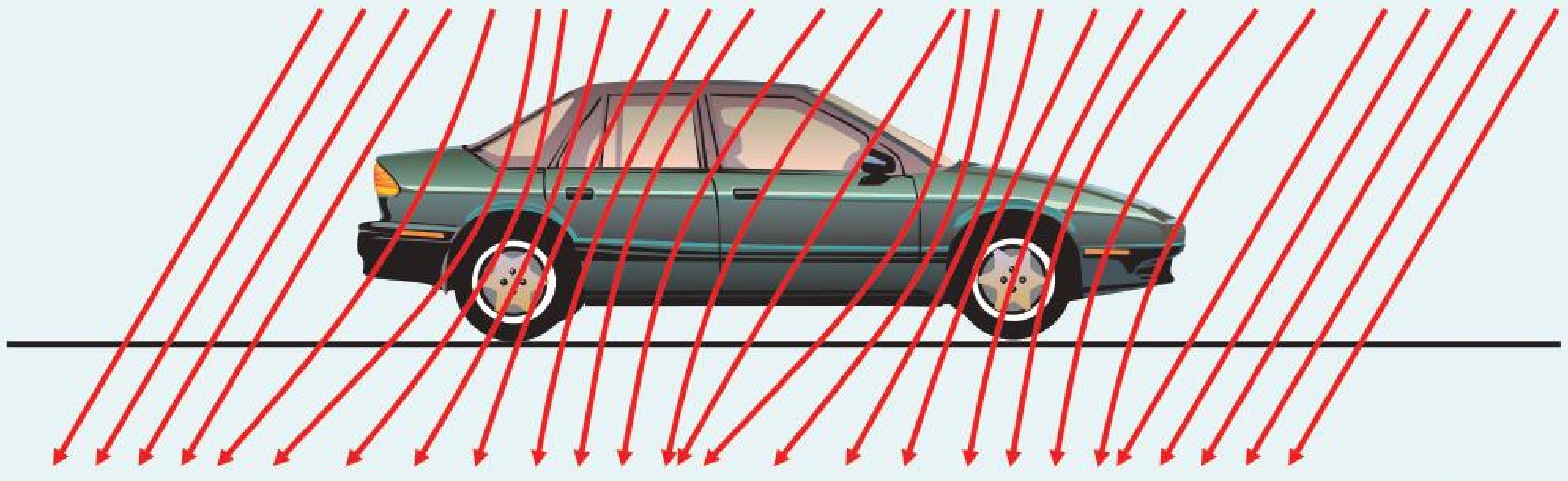


Fig.1: how the Earth's magnetic field is disturbed by a vehicle travelling along a driveway. These disturbances are detected by the magneto-resistive sensor used in the *Driveway Monitor*.

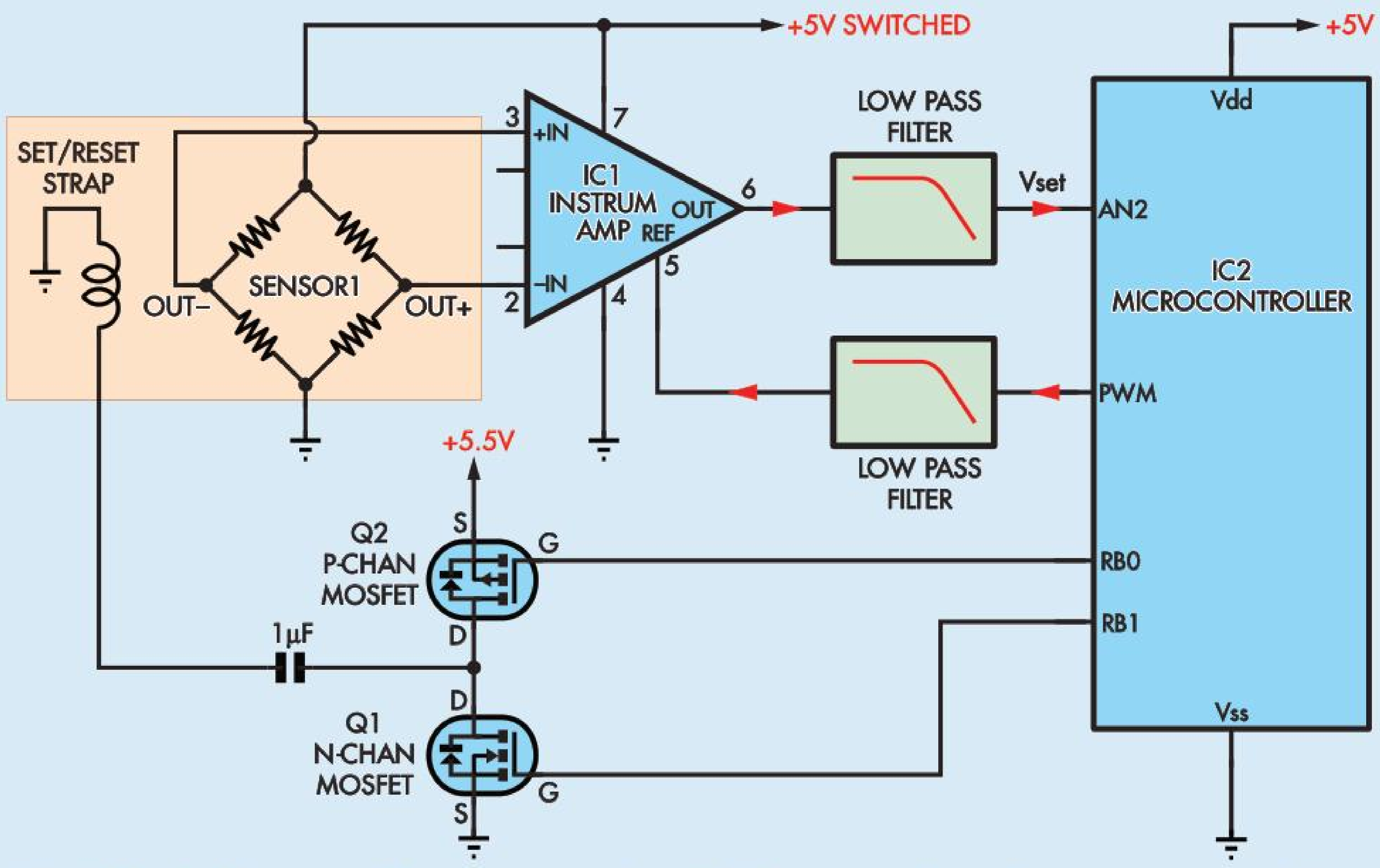


Fig.2: block diagram of the detector circuit. The output from the magneto-resistive sensor (Sensor1) is amplified by differential op amp IC1, which then feeds the AN2 input of microcontroller IC2 via a low pass-filter. IC2 then processes the amplified sensor signal and also drives MOSFETs Q2 and Q1 via its RB0 and RB1 outputs to provide set and reset signals to a strap coil in the sensor. In addition, IC2's PWM output applies an offset voltage to the REF input of IC1, so that IC1's pin 6 normally sits at 2.5V (half-supply).

resistive sensor, instrumentation amplifier IC1, PIC microcontroller IC2 and MOSFETs Q1 and Q2.

The magneto-resistive sensor is essentially a Wheatstone bridge of four resistors (which are affected by magnetic fields). The bridge is connected across a 5V supply and a change in the local magnetic field changes the resistor values so that the voltages at the sensor's outputs move up or down. This shift in the output terminals is monitored by differential instrumentation amplifier IC1.

Its output feeds microcontroller IC2 via a low-pass filter. If the magnetic field around the sensor changes, the micro sends an appropriately coded signal to a 433MHz transmitter module (not shown on Fig.2).

Strap coil

Each time the sensor detects a large change in the surrounding magnetic field, its magneto-resistors need to be reset by means of an internal 'strap coil' which provides a strong magnetic field. Hence the strap coil is subjected to a short reset signal from the micro. And in fact, before a measurement can be made, a 'set' signal must also be applied, again by the microcontroller (see the panel 'How a magneto-resistive sensor works' for further details).

The set and reset pulses appear at IC2's RB0 and RB1 outputs respectively, and these drive MOSFETs Q1 and Q2. The resulting pulses are fed to the strap resistor via a 1µF capacitor.

Each time IC2 takes RB0 low for a set pulse, Q2 switches on and current flows through the 1µF capacitor and the set/reset strap to ground (0V). The 1µF capacitor charges to +5.5V and Q2 and switches off . The amplified sensor output (Set) is then read at IC2's AN2 input.

Conversely, for the reset pulse, Q1 is switched on when RB1 is taken to +5V. The 1µF capacitor then discharges through the set/reset strap, with current now flowing in the opposite direction than for the set pulse. Q1 is then switched off to end the reset pulse and the amplified sensor output (Reset) is again read at the AN2 input.

IC2 then needs to apply an offset voltage to IC1 so that its output at pin 6 normally sits close to 2.5V and thereby ensure that its output swing is symmetrical. IC2 calculates this offset voltage by averaging the readings after the set and reset pulses. It then generates a pulse-width modulated signal at its PWM output and this is fed via a low-pass filter to pin 5 (REF input) of IC1.

The PWM signal generated by IC2 switches between 0V and 5V at 7.8kHz. Its duty cycle is automatically adjusted after each measurement to correct for any offset changes from both the sensor and IC1 due to temperature changes.

IC1's output is also low-pass filtered, to reduce any voltage ripple at IC2's AN2 input, due to the PWM signal, to a very low level. This allows microcontroller IC2 to detect voltage changes

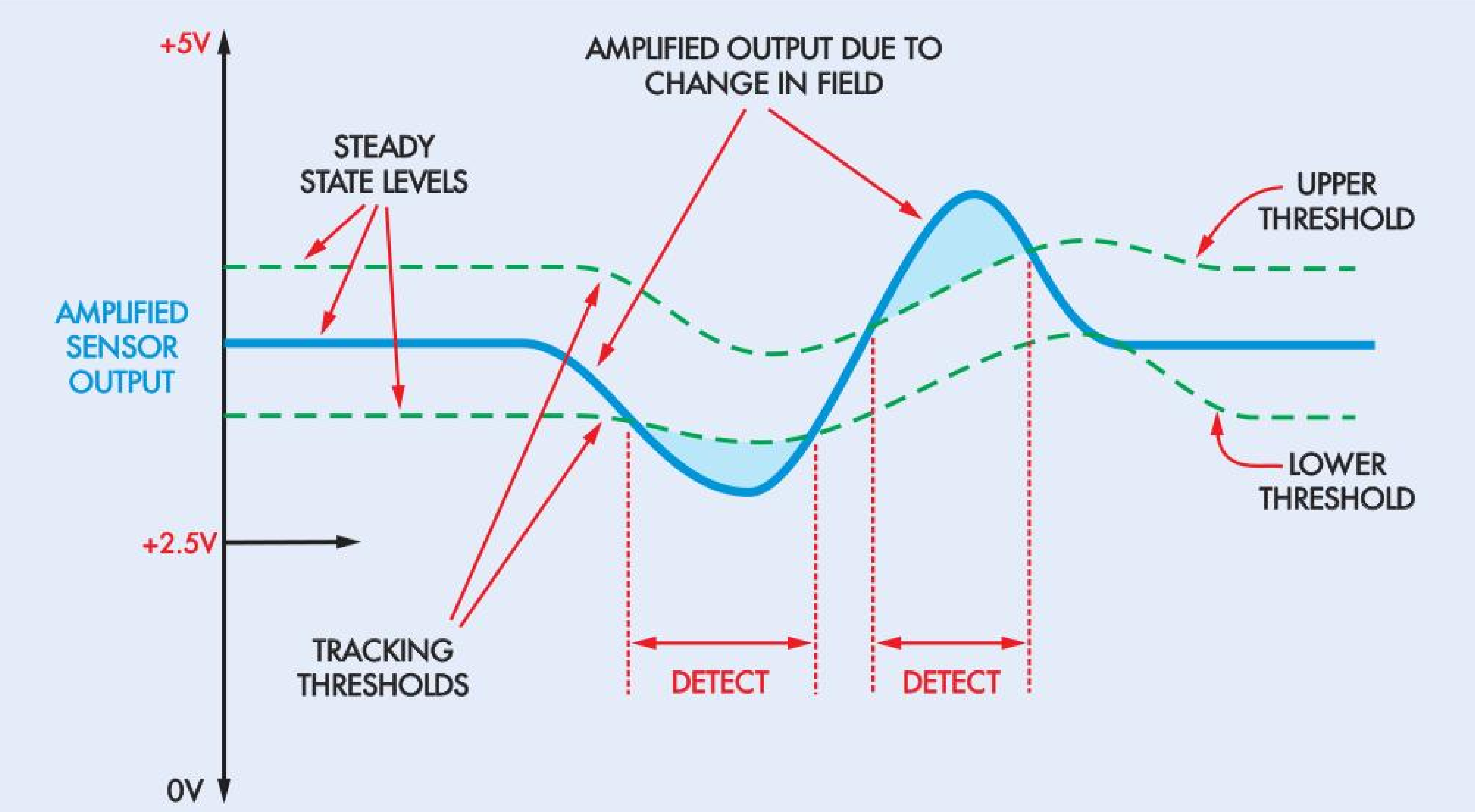


Fig.3: this diagram shows how IC1's pin 6 output changes when a vehicle comes close to the sensor. It either decreases and then rises as the vehicle approaches (as shown here) or it increases and then falls, depending on the orientation of the sensor and the direction of the vehicle. A vehicle is detected whenever the amplified sensor output exceeds the slowly-averaged upper and lower thresholds set by IC2 in response to IC1's steady-state output.

from the sensor as low as 5mV without being swamped by noise and ripple.

Detecting a vehicle

Fig.3 shows how IC1's output changes when a vehicle comes close to the sensor. As can be seen, it either decreases and then rises as the vehicle approaches or it increases and then falls, depending on the orientation of the sensor with respect to the Earth's magnetic field and the direction of the vehicle.

This enables the microcontroller to determine the vehicle's direction. A linking option on the PCB tells the microcontroller which is the entry direction and which is the exit direction.

IC2 detects a vehicle when IC1's output rises above an internally-generated upper threshold or falls below a lower threshold. These two thresholds are set equidistant above and below the steady-state amplified sensor output.

In operation, these upper and lower thresholds track the sensor's amplified output at a slow rate to compensate for any output changes with temperature (as well as slow magnetic field changes) over time. So, if the sensor's amplified DC output falls, the thresholds will also fall.

On the other hand, the tracking is slow enough to ensure that any quick changes in IC1's output level (ie, due to vehicle movement) will exceed the thresholds for brief periods. These are shown as the 'detect' periods on Fig.3. and when the thresholds are breached, the microcontroller determines that a vehicle has been detected.

Note that in order to conserve the battery, the detector circuit doesn't continuously monitor changes in the magnetic field. Instead, both the sensor and IC1 are powered for a brief period every 300ms and this is when IC2 samples IC1's output.

Circuit details

Now take a look at Fig.4, which shows the full circuit of the detector unit. The top section can be regarded as a more detailed version of the block diagram of Fig.2, but it also includes the 433MHz UHF transmitter module TX1, PNP transistors Q3 and Q4 and a switching power supply.

Q3 and Q4 are respectively driven by RB2 and RA3 of IC2 and switch power to the sensor, IC1 and the UHF transmitter module every 300ms, as mentioned above. The switched 5V supply rail from Q3 is decoupled using a 1µF electrolytic capacitor and a 100nF ceramic capacitor.

The power supply uses a TL499A switch-mode step-up regulator (REG1), a linear 5V regulator (REG2) and an LMC6041 micropower op amp (IC3). As stated above, it's powered from a 1.25V NiMH AA cell that's topped up by a solar panel.

Alternatively, by cutting a track on the PCB and installing resistor R1, a 9V or 12V DC supply can be used to maintain cell charge if a mains supply is available.

The 5V rail from REG2 directly powers microcontroller IC2 and is switched to sensor 1 and IC1 by Q3 and to the TX1 module by Q4. Sensor 1 draws a current of about 5mA each time it is briefly powered up.

The Out+ and Out– terminals are fed to the IN– and IN+ inputs of IC1 via ferrite beads, while the 1nF bypass capacitors to ground attenuate any RF signals. In addition, a 100nF capacitor

Main Features

- Remote vehicle detection with adjustable detection sensitivity
- Vehicle detection LED indication
- Vehicle direction detection
- Solar panel and NiMH cell powered
- Transmits vehicle detection via UHF link to the receiver
- Typical UHF range: 200m in open space
- Eight possible UHF transmission identities to allow for multiple *Driveway Monitor* pairs to be used in close proximity
- Selectable vehicle entry only or exit only detection, or both entry and exit detection
- Optional non-directional indication
- Vehicle direction detection setting to cater for detector positioning and driveway orientation
- Over-range indication (flashes red and green LEDs in detector unit) alternately
- Diagnostic setting
- Receiver has audible and visible indication of vehicle detection
- Receiver produces different sounds for exit and entry unless non-direction detection is selected on the detector unit
- Detection sampling rate: typically 300ms
- Set and reset pulses: every 10s.

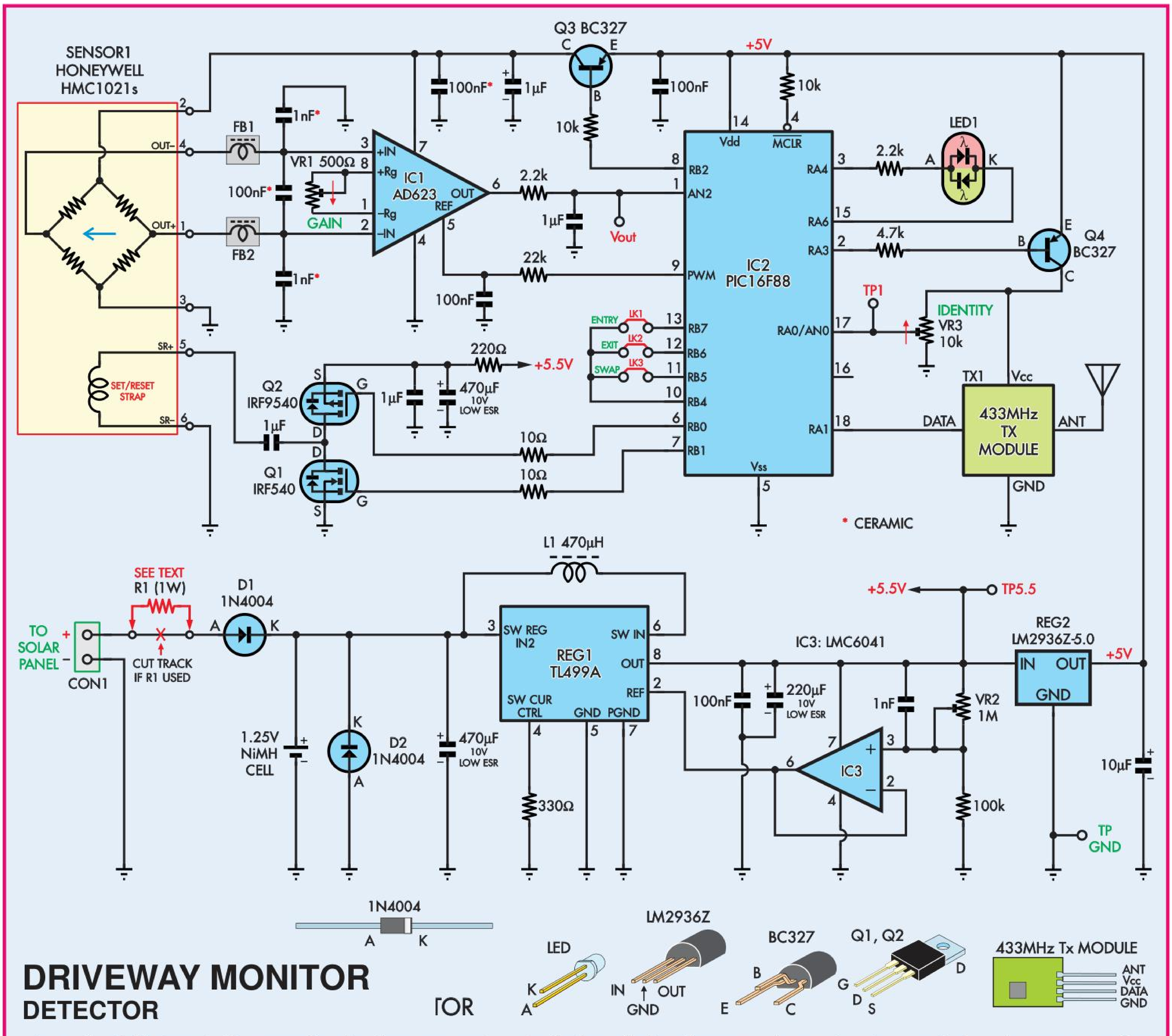

SENSOR1
HONEYWELL
HMC1021s
OUT–
OUT+
SR+
SR–
SET/RESET STRAP
FB1
FB2
1nF*
100nF*
VR1 500Ω
GAIN
IC1
AD623
+IN
+Rg
–Rg
–IN
OUT
REF
Q3 BC327
C
E
B
10k
100nF*
1µF
100nF
+5V
2.2k
1µF
Vout
22k
100nF
IC2
PIC16F88
Vdd
MCLR
RB2
AN2
PWM
RB7
RB6
RB5
RB4
RB0
RB1
Vss
RA4
RA6
RA3
RA0/AN0
RA1
LED1
A
K
2.2k
4.7k
Q4
BC327
TP1
IDENTITY
VR3
10k
TX1
Vcc
433MHz
TX
MODULE
DATA
ANT
GND
ENTRY
EXIT
SWAP
LK1
LK2
LK3
220Ω
+5.5V
1µF
470µF
10V
LOW ESR
Q2
IRF9540
Q1
IRF540
S
G
D
1µF
10Ω
10Ω
* CERAMIC
L1 470µH
SEE TEXT
R1 (1W)
D1
1N4004
TO SOLAR PANEL
CON1
CUT TRACK IF R1 USED
1.25V
NiMH
CELL
D2
1N4004
470µF
10V
LOW ESR
REG1
TL499A
SW REG IN2
SW IN
OUT
REF
SW CUR CTRL
GND
PGND
330Ω
100nF
220µF
10V
LOW ESR
IC3: LMC6041
IC3
1nF
VR2
1M
100k
+5.5V
TP5.5
REG2
LM2936Z-5.0
IN
OUT
GND
+5V
10µF
TP
GND
1N4004
A
K
LED
K
A
LM2936Z
IN
OUT
GND
BC327
B
E
C
Q1, Q2
G
D
S
433MHz Tx MODULE
ANT
Vcc
DATA
GND
DRIVEWAY MONITOR
DETECTOR

Fig.4: the full circuit diagram for the detector unit. It includes all the elements shown in Fig.2 and also shows LED1 (for exit and entry indication) and the 433MHz transmitter (TX) module, which is driven by IC2's RA1 port. Q3 briefly switches power to the sensor and IC1 at 300ms intervals while Q4 briefly switches power to the TX module, to minimise current consumption. Power comes from a 1.25V NiMH cell topped up by a solar cell. Switching regulator REG1 steps up the cell voltage to produce a 5.5V rail for Q2 and Q1; REG2 produces a regulated 5V rail for the rest of the circuit.

bypasses the IN+ and IN– inputs to provide further RF suppression.

IC1 is an Analog Devices AD623 differential amplifier and it draws about 300µA from the 5V supply. Its gain is adjusted using trimpot VR1 and can be varied from about 201 times when VR1 is set to 500Ω (its maximum) up to about 1000 times when VR1 is set to 100Ω.

IC2's PWM signal is fed to pin 5 (REF) of IC1 via a low-pass filter consisting of a 22kΩ resistor and a 100nF capacitor. The filter sets the roll-off frequency to about 72Hz and this effectively removes a considerable amount of the 7.8kHz PWM switching frequency.

However, by itself that is not effective enough to remove sufficient PWM ripple and so IC1's output also has low-pass filtering, using a 2.2kΩ resistor and 1µF capacitor.

Microcontroller IC2 (a PIC16F88) converts the voltage at its AN2 (pin 1) input into a digital value using a 10-bit A-D converter. This gives a resolution of close to 4.9mV. The variation available for the PWM output also has 10-bit resolution, allowing IC1's offset voltage to be set in 4.9mV increments.

Set and reset signals

MOSFET Q2 is driven by IC2's RB0 output and provides the set pulse drive current, while Q1 is driven by RB1 and provides the reset pulse drive for Sensor1's set/reset strap.

This strap is a coil with about 7.7Ω resistance and it produces the high magnetic field required to realign the elements in the sensor along the 'easy' axis (see the further description of the workings of the magneto-resistive sensor in the panel below).

As shown on Fig.4, Q2's source is connected to the +5.5V supply rail via

How a magneto-resistive sensor works

The Honeywell HMC1021S sensor used in this project is a one-axis type. In essence, this means that it only reacts to changes in the horizontal component of the Earth's magnetic field (assuming that it is installed on a vertical PCB.

Fig.5 shows the basic construction of this type of sensor, which comprises four identical resistive elements arranged in a Wheatstone bridge configuration.

Each element is basically an NiFe (nickel-iron) thin film that changes its resistance in response to changes in the magnetic field passing through it. Whether an element increases or decreases its resistance with magnetic field strength depends on its orientation and the magnetic field polarity.

Fig.5 shows how the elements in the sensor are arranged. Two diagonally opposite elements are oriented one way, while the other two are oriented in the opposite direction, in the Wheatstone bridge. Because of its sensitivity to magnetic field direction, a magneto-resistive sensor is often called an 'anisotropic magneto-resistive' sensor or AMR. The term 'anisotropic' simply means directional.

In operation, a supply voltage is applied between the top and bottom of the bridge (ie, between its Vb and GND terminals), so a current flows through the elements. If a magnetic field is absent, the OUT+ and OUT– terminals are both at half supply (ie, Vb/2).

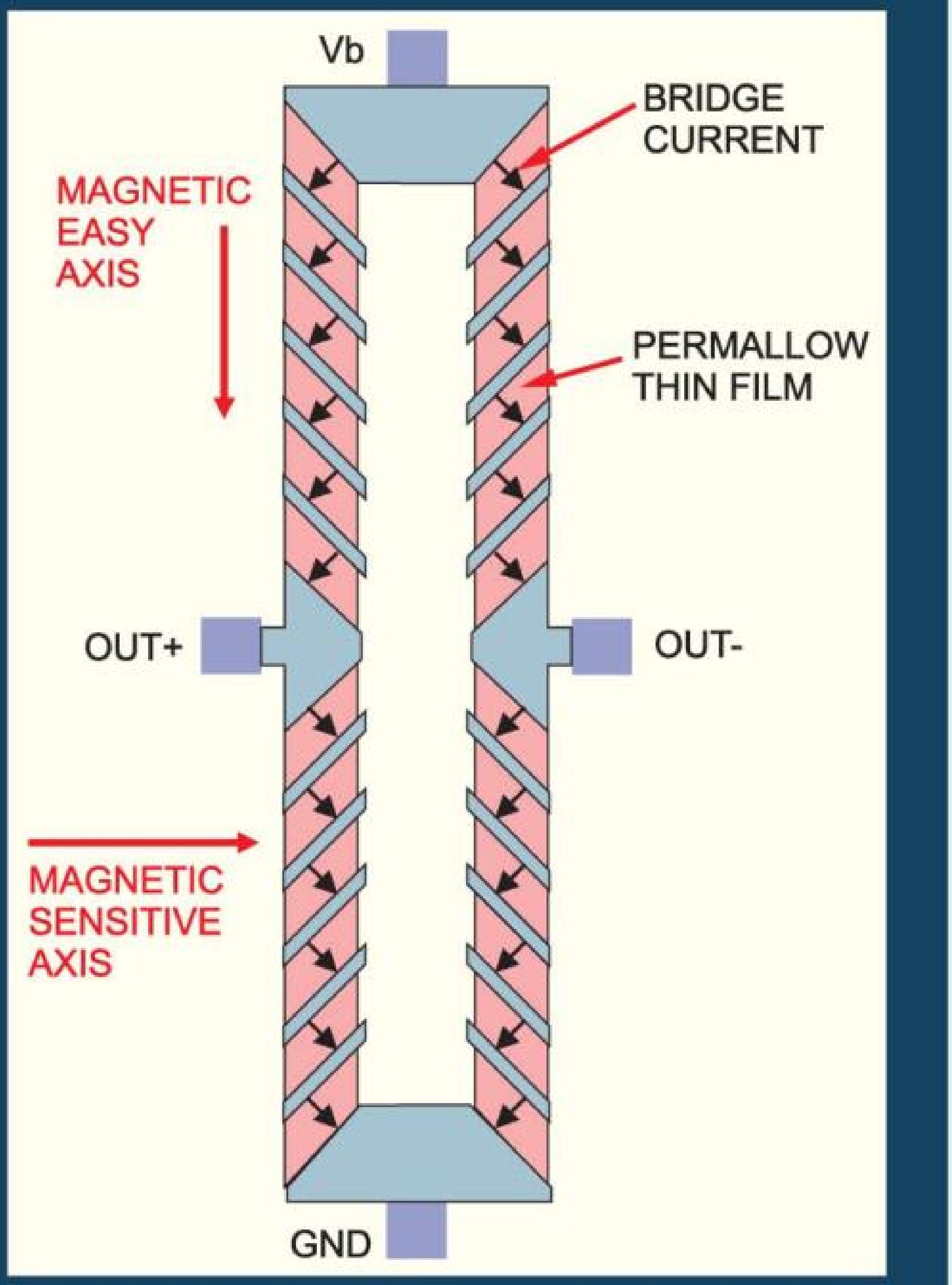


Fig.5: the magneto-resistive sensor consists of four identical thin-film elements arranged in a Wheatstone bridge configuration. Two diagonally opposite elements are oriented one way, while the other two face in the opposite direction.

By contrast, if a magnetic field is present, two diagonally opposite elements will decrease in resistance while the other two diagonally opposite elements will increase in resistance. As a result, the OUT+ and OUT– terminals will change voltage by equal amounts but in different directions.

In other words, one terminal will rise above half-supply by a certain amount, while the other will fall below half-supply by an equal mount.

Offset voltage

That's the basic theory of the sensor operation. In practice though, real sensors have an offset voltage between OUT+ and OUT– in the absence of a magnetic field. That's because when the sensor elements are made, there will always be small variations between them, thereby causing an imbalance in the bridge. In addition, this offset voltage will vary with temperature.

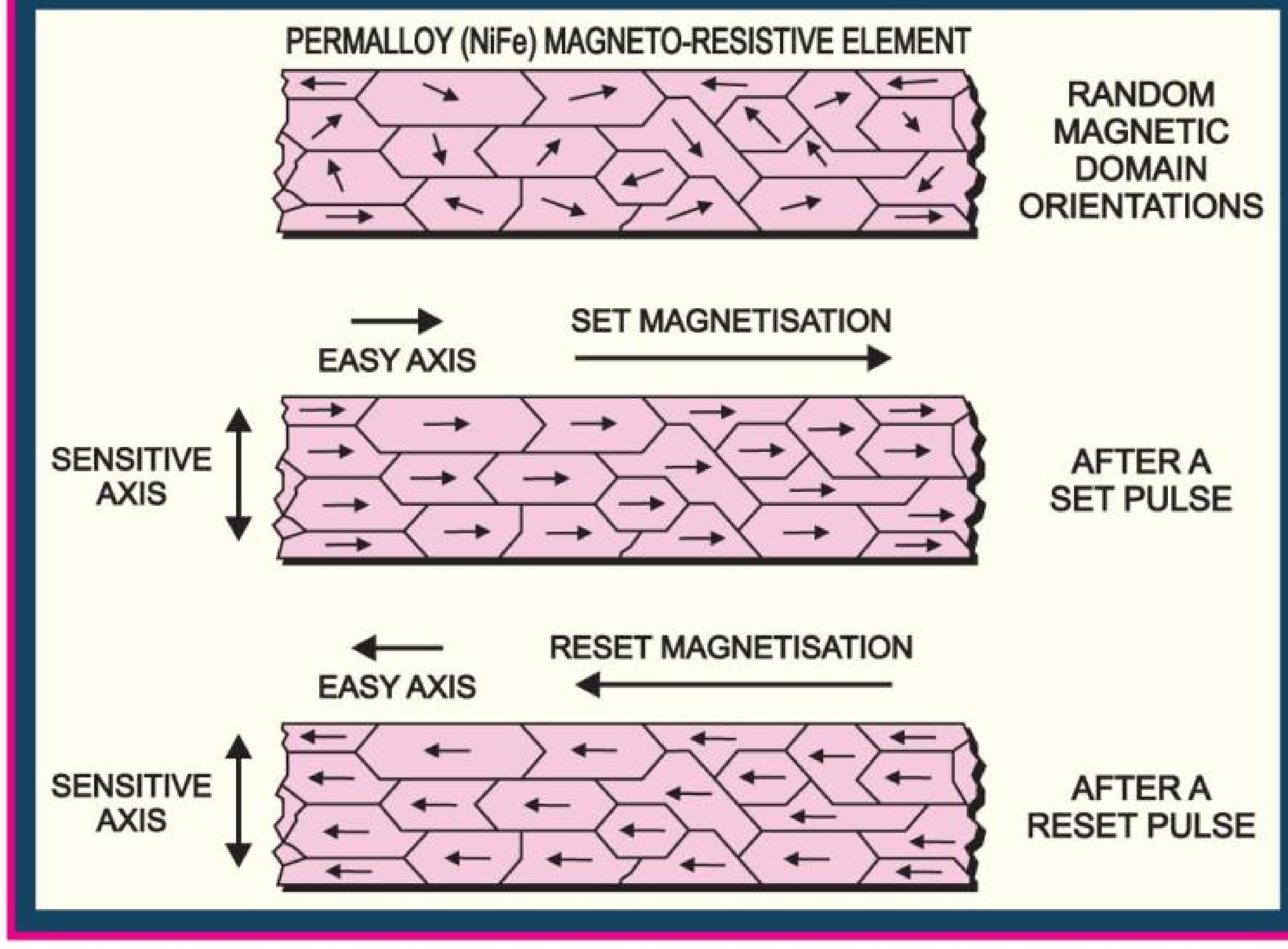


Fig.6: the set and reset pulses applied to the strap coil inside the sensor align the magnetic domains in the resistive element along the easy axis.

Another problem is that the magnetic domains in the sensor elements can move out of alignment in the presence of strong magnetic fields. Basically, the domains in the elements must be orientated along what is called the 'easy' axis and this is the alignment that the magnetic domains are set to during manufacture. Fig.6 shows the general idea.

Correct easy axis alignment is necessary to ensure maximum sensitivity of the sensor to magnetic fields. The most sensitive direction for magnetic field detection is perpendicular (ie, at a right angles) to the easy axis. Any external magnetic field (or a portion of that field) that is not parallel to the easy axis will cause the magnetic domains to rotate away from the easy axis and this alters the resistance of the sensor element.

Conversely, when the magnetic field is removed, the magnetic domains return to their easy axis alignment, provided that the magnetic field does not exceed the specified operating range for the sensor.

Set and reset pulses

In practice, this all means that the sensor will periodically need to be set and reset using a high magnetic field, to realigns the magnetic domains along the easy axis. This set and reset procedure is achieved by applying a pulse current to the strap coil incorporated within the sensor.

The set and reset currents used are opposite in polarity. When the coil is driven with one current polarity, it produces a magnetic field that aligns the domains in one direction along the easy axis. Reversing the current direction through the sensor's coil then aligns the domains in the other direction (ie, it rotates them by 180°).

Fig.7 shows the effect of the set and reset pulses on the sensor's output. As shown, a brief set pulse produces a large output from the sensor, due to the large magnetic field produced by this pulse.

Following the set pulse, the output from the sensor goes down to Vset, which is the voltage difference between Out+ and Out–. This voltage is shown as being above the offset voltage (Voff) of the sensor and is produced in response to an external magnetic field.

A reset pulse then follows, after which

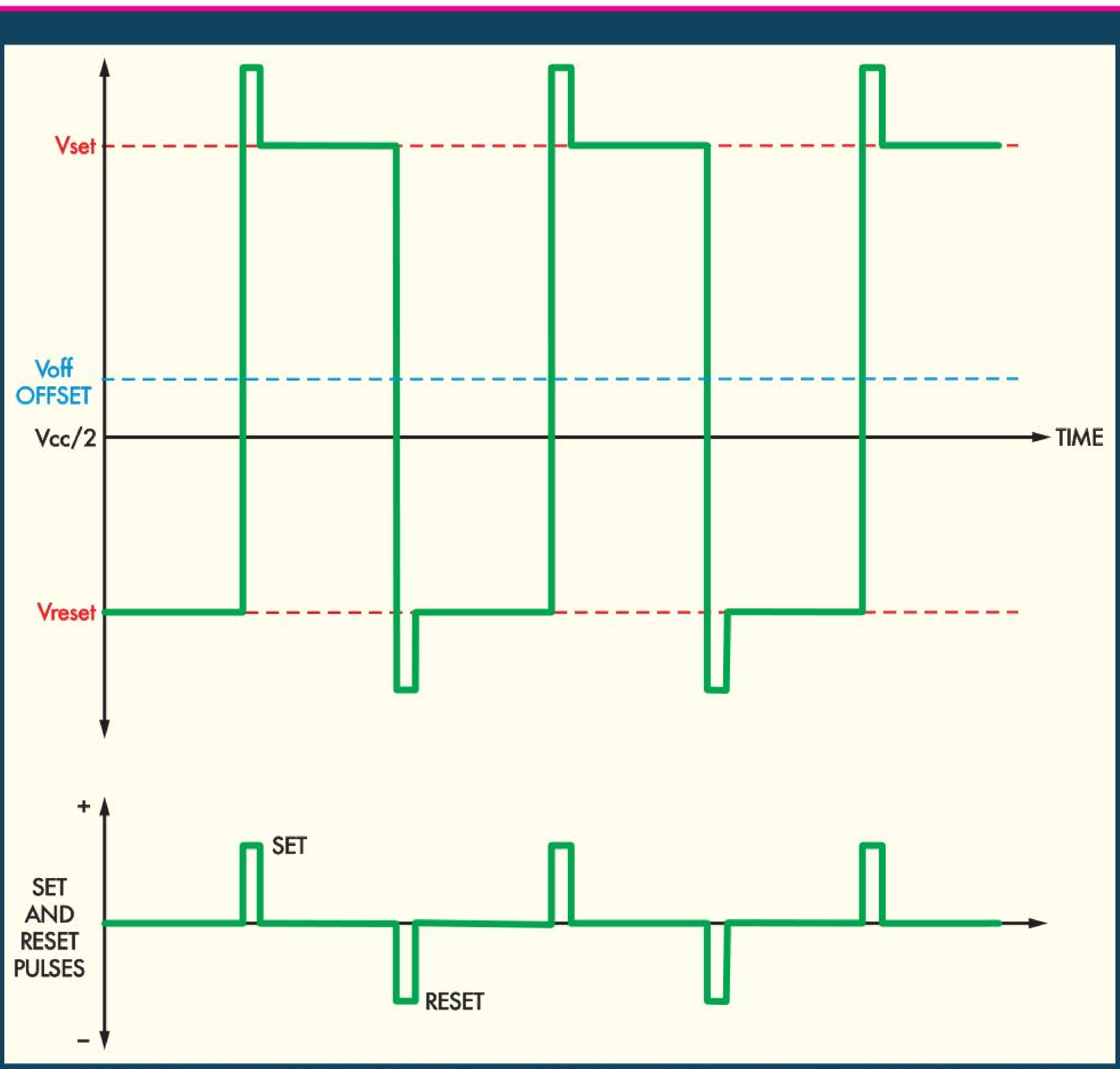


Fig.7: this diagram shows the effect of the set and reset pulses on the sensor's output. Note that the output polarity switches after each pulse.

the output from the sensor goes to Vreset. This again is the voltage difference between Out+ and Out– and is now below Voff.

Note that after a set pulse, a subsequent reset pulse switches the polarity of the sensor's output voltage. Similarly, after a reset pulse, a set pulse switches the output polarity back again.

Fig.7 only applies for one direction of the magnetic field. If the field is reversed, then the polarities of Vset and Vreset are also reversed. In other words, Vset will be lower than Voff after a set pulse, while Vreset will be higher than Voff after a reset pulse.

By contrast, the sensor's offset voltage (Voff) is unaffected by magnetic field variations – it's only the sensor's output that varies. In the absence of a magnetic field, the offset Voff would simply be the difference between Out+ and Out–. In practice though, the device operates in the presence of the Earth's magnetic field.

In summary, we need the set and reset pulses to realign the magnetic domains in the sensor to ensure maximum sensitivity. As a bonus, this also provides a means to calculate the sensor's offset voltage (Voff) and thus compensate for it. That's done by simply adding the Vset and Vreset values together and dividing by two. Calculating Voff at regular intervals then allows us to compensate for offset changes with temperature.

Why compensate for offset?

But why do we need to compensate for the sensor offset? The reason is that changes in the sensor's output in response to magnetic field variations are quite small and so we need to amplify its output. Assuming a 5V supply (as in this circuit), the output varies by around 2.5mV, depending on the sensor's orientation within the Earth's magnetic field (approximately 50µ tesla or 0.5 gtauss).

By contrast, the sensor's offset could be up to 11.25mV. So if a 2.5mV signal is amplified by say 500 to obtain a 1.25V signal, the 11.25mV offset voltage would also be amplified by 500 to a level of 5.6V.

That means that unless we compensate for the sensor's offset voltage, the amplified signal could result in the amplifier's output being pegged at either the positive or 0V supply rail, with no resulting change in level due to magnetic field variations.

a 220Ω isolating resistor and decoupled using a 470µF low-ESR capacitor and a 1µF MKT capacitor. The set pulse current is applied to the strap via the 1µF capacitor as it charges when Q2 turns on, while the discharge current from this 1µF capacitor provides the reset pulse when Q1 turns on.

Both the charge and discharge peak currents are in excess of the 500mA minimum required for this operation.

The accompanying oscilloscope traces (Fig.8 and Fig.9) show the set and reset pulses. In each case, the top trace is the drain voltage of Q2 and Q1, while the lower trace is the pulse applied to the set/reset strap of the sensor. Note that the set pulse is a positive voltage, while the reset pulse is negative.

Note also that there is a small amount of 'dead time' between when Q2 is switched off and Q1 is switched on. This ensures that they aren't both on at the same time (however briefly) which is necessary to prevent a momentary short across the decoupled supply rail.

In operation, RB0 and RB1 of IC2 drive the MOSFET gates every 10s and both the set and reset pulses decay away over time. These pulses produce a magnetic field in the sensor, so the amplified sensor signal from IC1 is checked by IC2 only while both Q1 and Q2 are switched off to ensure that only variations in the Earth's magnetic fields are detected.

Detection and link options

As previously mentioned, the voltage fed by IC1 to AN2 of IC2 is compared against high and low threshold voltages that track AN2's voltage at a slow rate. Whenever AN2's voltage varies, the thresholds are adjusted up or down by 4.8mV every 1.5s. However, a moving vehicle will cause AN2's signal voltage to vary by considerably more than 4.8mV in much less than 1.5s and so the thresholds will be exceeded.

IC2 detects whenever AN2 goes below the lower threshold or above the upper threshold and drives a bi-colour red/green LED (LED1). The green LED lights for five seconds if AN2's voltage initially goes below the lower threshold; the red LED lights for 5s if it goes above the upper threshold. During this time, the detection process is disabled.

At the same time, a vehicle detection signal is sent to the receiver circuit by

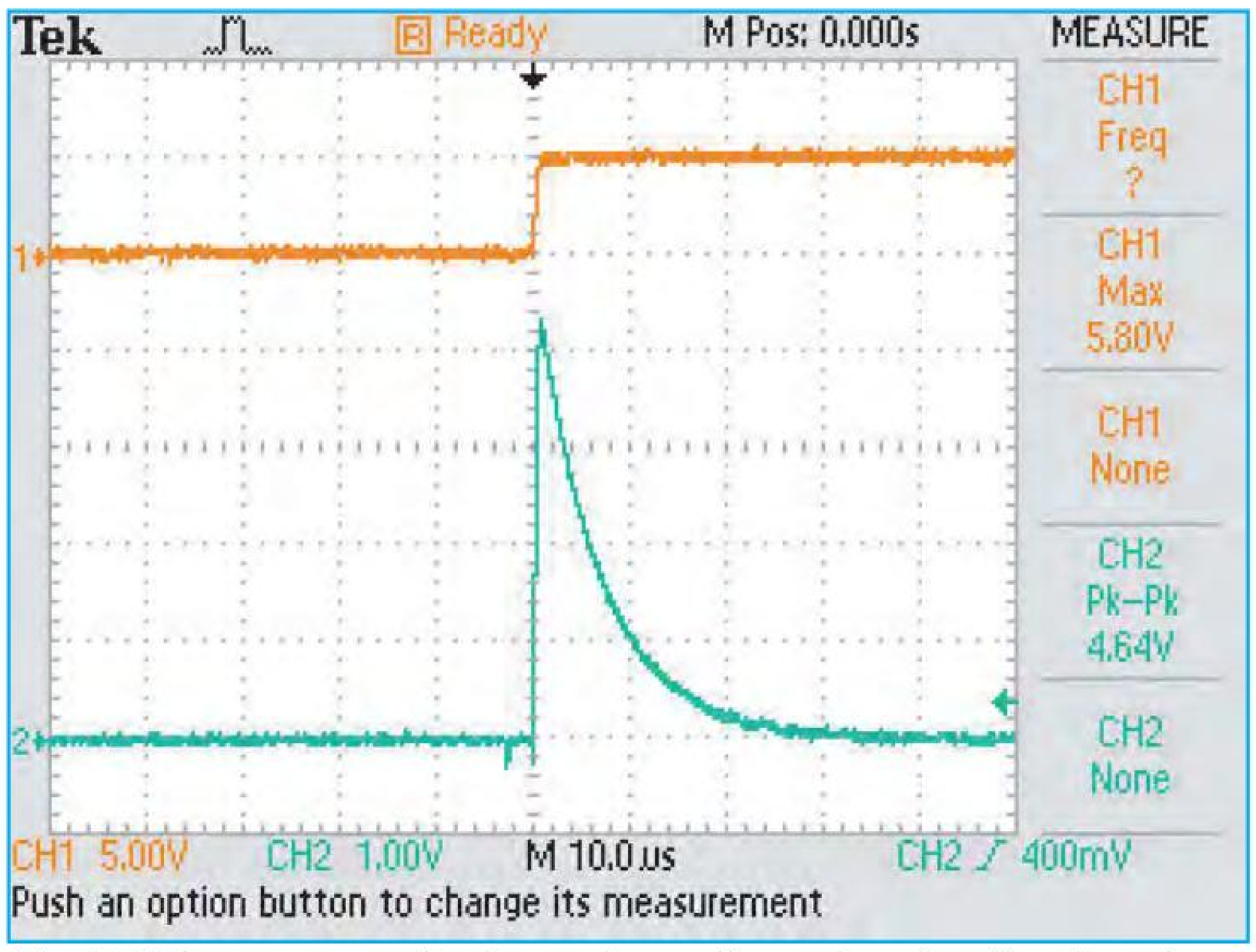

Tek
Ready
M Pos: 0.000s
MEASURE
CH1 Freq ?
CH1 Max 5.80V
CH1 None
CH2 Pk–Pk 4.64V
CH2 None
1
2
CH1 5.00V
CH2 1.00V
M 10.0µs
CH2 ∕ 400mV
Push an option button to change its measurement

Fig.8: this scope grab shows how the set pulse for the strap coil is generated. Each time IC2's RB0 output briefly goes high, MOSFET Q2 switches on and the commoned MOSFET drains go high as shown by the orange trace. The bottom green trace shows the resulting positive-going set pulse that's then applied to the strap coil via the 1µF capacitor.

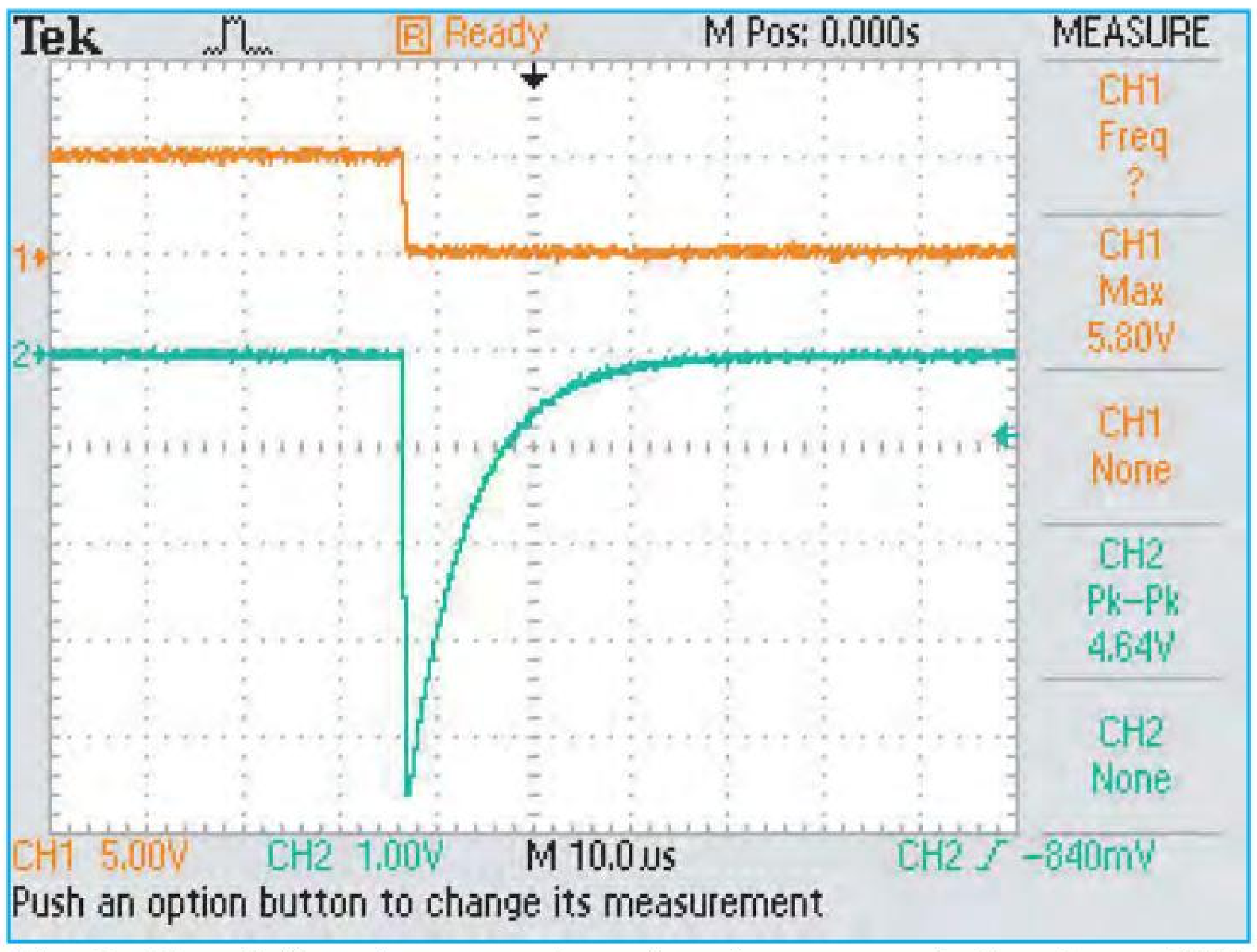

Tek
Ready
M Pos: 0.000s
MEASURE
CH1 Freq ?
CH1 Max 5.80V
CH1 None
CH2 Pk–Pk 4.64V
CH2 None
1
2
CH1 5.00V
CH2 1.00V
M 10.0µs
CH2 ∕ −840mV
Push an option button to change its measurement

Fig.9: the following reset pulse is generated when RB1 subsequently briefly goes high. This turns on MOSFET Q1 and the commoned MOSFET drains are then pulled to 0V as shown by the orange trace. A negative-going reset pulse (green trace) is then generated as the 1µF capacitor discharges

the 433MHz transmitter (TX) module, depending on the linking options selected for LK1, LK2 and LK3.

LK1 is used if you want entry (arrival) notifications to be transmitted, while LK2 is installed if you want exits (departures) to be transmitted. Either LK1 or LK2 can be installed, or both can be installed to warn of both arrivals and departures.

LK3 is the 'swap' link and is used to set the unit so that it correctly identifies the vehicle's direction (entry or exit). This direction indication initially depends on the orientation of the driveway and which side of the driveway the detector unit is mounted on. If the directions are incorrect, it's just a matter of installing the link.

Installing LK3 swaps the exit/entry transmission codes that are sent to the receiver and the detection LED colour.

Non-directional signalling

Yet another link option (not shown on Fig.4) forces the *Driveway Sentry* to send a non-directional signal to the receiver unit, instead of separate entry and exit signals. That's done by installing a link between LK1 and LK2 to short pins 12 and 13 of IC2. The receiver unit then simply indicates that a vehicle has passed by the detector without indicating its direction.

Yet another option is to install a link between LK2 and LK3 to short pins 11 and 12 of IC2. This is a diagnostic connection and we'll describe this in greater detail next month.

IC2 determines which links have been installed by first pulling its RB5, RB6 and RB7 inputs high (ie, to +5V). Its RB4 output is then pulled low (0V) and the RB5-RB7 inputs checked to see if any of these are also now low. If so, then a jumper link must be installed on that particular input.

Determining if there is a connection between RB7 and RB6 or between RB6 and RB5 is only slightly more complicated. It's done by first making RB6 an output and RB4 an input. RB6 is then taken both low (0V) and high (5V) and RB7 and RB4 checked to see if either one follows RB6. If an input follows, then there is a jumper link between it and RB6.

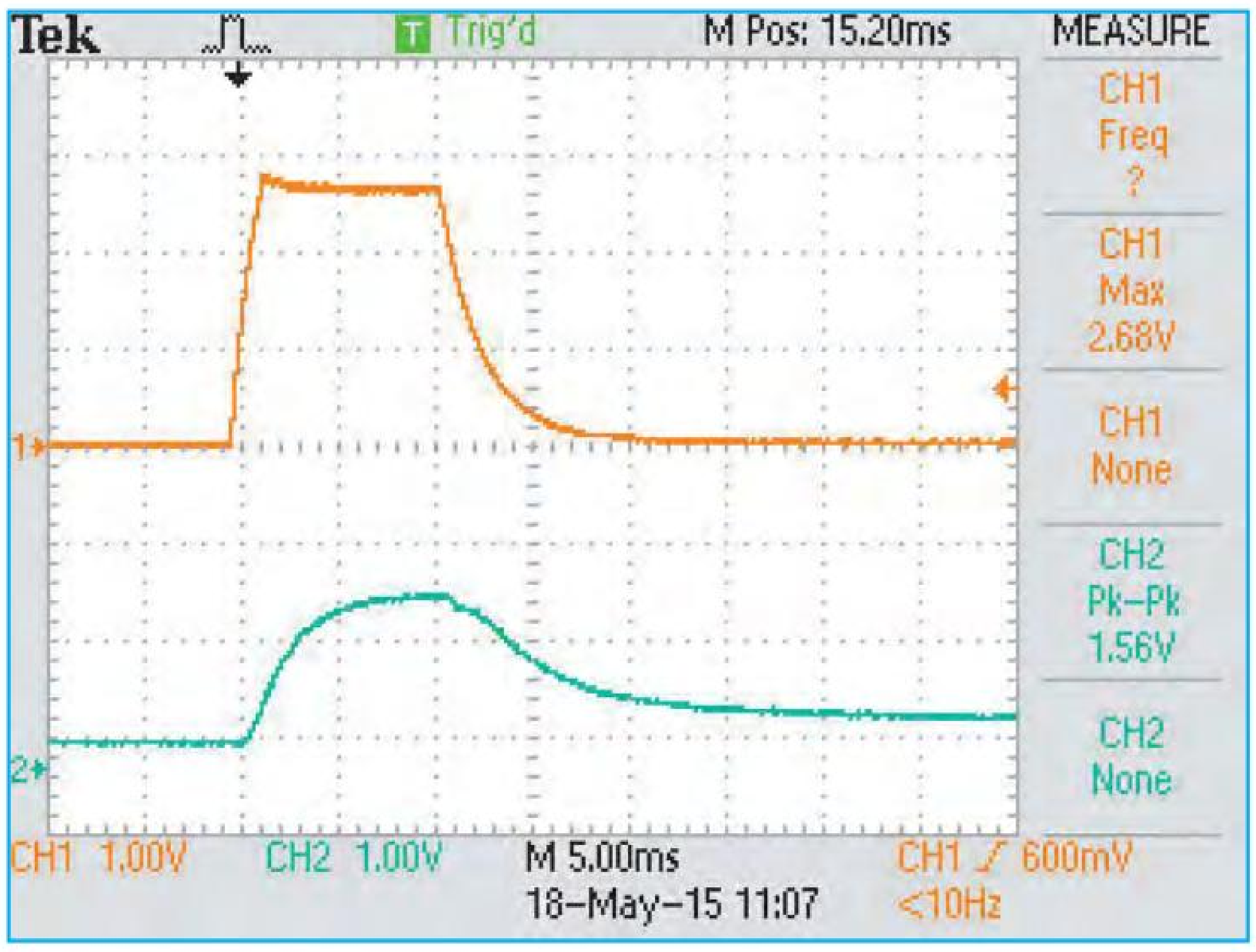

Tek
Trig'd
M Pos: 15.20ms
MEASURE
CH1 Freq ?
CH1 Max 2.68V
CH1 None
CH2 Pk–Pk 1.56V
CH2 None
1
2
CH1 1.00V
CH2 1.00V
M 5.00ms
18–May–15 11:07
CH1 ∕ 600mV
<10Hz

Fig.10: the top trace in this scope grab shows the reference voltage applied to pin 5 of IC1, while the bottom trace shows the filtered output from pin 6 that's fed to IC2's AN2 input. The reference voltage is about 180mV above the half supply of 2.5V to compensate for the sensor's offset.

433MHz UHF transmitter

TX1 is the 433MHz transmitter module. Its supply line is switched by Q4 and this transistor is turned on by IC2's RA3 output whenever transmission is required (ie, Q4 turns on when RA3 goes low).

Trimpot VR3 is also connected to the +5V supply rail when Q4 turns on. Its wiper is monitored via IC2's AN0 input and the set voltage is included in the UHF transmission as identity information. This voltage then needs to match the voltage set on a similar trimpot in the receiver unit in order for the transmission to be accepted (ie, in order for pairing to take place).

There are eight valid voltage ranges that can be set using VR3 to select one of eight different identities. As a result, up to eight different detector and receiver pairs can operate independently in close proximity.

Conserving the battery

As already noted, Sensor1 draws about 5mA and the AD623 amplifier

Parts List: Detector Unit

Detector Unit

- 1 PCB available from the *EPE PCB Service*, coded 15105151, 104 × 78mm
- 1 IP65 polycarbonate enclosure, 115 × 90 × 55mm
- 1 single AA cell solar panel and wiring
- 1 AA cell holder
- 1 NiMH AA cell
- 1 powdered-iron toroidal core, 15 × 8 × 6.5mm
- 1 2-way PCB-mount screw terminal with 5.08mm spacing
- 1 UHF transmitter (TX1)
- 1 3-way DIL pin header strip (2.54mm spacing)
- 3 pin header shunts
- 1 18-pin DIL IC socket
- 3 8-pin DIL IC sockets (optional)
- 1 cable gland for 3-6.5mm cable
- 7 PC stakes
- 2 No.4 × 6mm self-tapping screws
- 4 M3 × 6mm screws
- 2 5mm ferrite beads
- 2 100mm cable ties
- 1 50mm length of tinned copper wire
- 1 750mm length of 0.5mm-diameter enamelled copper wire
- 1 170mm length of light duty hook-up wire
- 1 500Ω miniature horizontal-mount trimpot (code 501) (VR1)
- 1 1MΩ miniature horizontal-mount trimpot (code 105) (VR2)
- 1 10kΩ miniature horizontal-mount trimpot (code 103) (VR3)

Semiconductors

- 1 Honeywell HMC1021S one-axis magneto-resistive sensor (Sensor1)
- 1 AD623AN instrumentation amplifier (IC1)
- 1 PIC16F88-I/P microcontroller programmed with 1510515A.hex (IC2)
- 1 LMC6041IN CMOS micropower op amp (IC3)
- 1 TL499A power supply controller (REG1)
- 1 LM2936Z-5.0 low dropout 5V regulator (REG2)
- 1 IRF540 N-channel MOSFET (Q1)
- 1 IRF9540 P-channel MOSFET (Q2)
- 2 BC327 PNP transistors (Q3,Q4)
- 2 1N4004 1A 400V diodes (D1,D2)
- 1 bi-colour LED (two lead) LED1

Capacitors

- 2 470µF 10V low-ESR electrolytic
- 1 220µF 10V low-ESR electrolytic
- 1 10µF 16V PC electrolytic
- 1 1µF 16V PC electrolytic
- 3 1µF MKT polyester
- 3 100nF MKT polyester
- 2 100nF ceramic
- 1 1nF MKT polyester
- 2 1nF ceramic

Resistors (0.25W, 1%)

- 1 100kΩ
- 1 22kΩ
- 2 10kΩ
- 1 4.7kΩ
- 2 2.2kΩ
- 1 330Ω
- 1 220Ω
- 2 10Ω

(IC1) about 300µA from the 5V supply when connected via Q3. That's a total of 5.3mA from the 5.5V output of REG1, and means that around 25mA would be drawn from the single 1.25V AA cell that powers everything (taking into account power conversion and efficiency).

Because of this, a number of steps have been taken to minimise the power consumption. First, as previously mentioned), Sensor1 and IC1 are only powered up each time a measurement is required and that's done for only about 20ms at 300ms intervals. This 20ms duration was chosen to give sufficient time for the filters at IC1's reference (REF) input and at its output to settle (ie, much longer than the low-pass filter time constants of 2.2ms).

As a result, the power on/off ratio is 1/15 and so the average current drawn from the 5V supply is just 5.3mA × 1/15th = 353µA.

The 433MHz UHF module draws 10mA when powered, while VR3 draws a further 500µA. However, they draw very little power overall, since they are only powered up when a UHF transmission is required (ie, when a vehicle is detected).

Even if a vehicle stops next to the detector, the unit will quickly stop transmitting as the upper and lower thresholds catch up to the voltage on IC2's AN2 pin.

Further power is saved by shutting down microcontroller IC2 so that it is in sleep mode for most of the time and drawing a maximum current of just 11µA. This current is much lower than when actually running its internal program and drawing up to 2.8mA.

In operation, IC2 is woken up for 20ms every 300ms by a watchdog timer that runs while it is in sleep mode (ie, 2.8mA is drawn for just 20ms every 300ms). This means that IC2's average current is just 187µA.

An additional power saving has been made by having IC2's RB4 output normally set high, so any jumper links that are inserted do not cause the internal pull-up current to flow. This can save up to 1.2mA if all the links are in place. In operation, RB4 is taken momentarily low when the link connections need to be checked, but again the overall average current is quite small.

Power supply circuit

The single 1.25V AA cell's output is stepped up to 5.5V using a step-up regulator, REG1. Regulator REG2 is then used to derive the 5V rail.

This second regulator helps remove any switching noise from the output of the step-up regulator and provides a well-regulated 5V supply to power Sensor1, IC1, IC2 and the 433Hz TX module.

In greater detail, REG1 is a TL499A step-up regulator. In operation, current flows through inductor L1 each time REG1's SW IN output (pin 6) switches low. When this reaches a peak value, the SW IN output is switched off and the stored energy in the inductor is fed via an internal diode to the pin 8 output. This output is then filtered using a 100nF MKT capacitor and a 220µF low-ESR capacitor.

The 330Ω resistor between pin 4 of REG1 and ground sets the peak current through the inductor to about 300mA. Voltage regulation is achieved by sampling the output voltage using a resistive divider (VR2 and 100kΩ) and then feeding this sampled voltage to the reference input at pin 2. In this case, the inductor switching rate must be adjusted so that pin 2 is kept at 1.26V.

This means that for a 5.5V output, the voltage divider needs to reduce the 5.5V down to 1.26V and that's done with VR1 set to 336kΩ.

The voltage from the divider is then buffered using op amp IC3 (which is configured as a voltage follower) before being fed to pin 2 of REG1. This buffer stage allows the use of higher-value divider resistors than would otherwise be the case, again done to minimise power consumption.

Parts List: Receiver Unit

1 PCB available from the *EPE PCB Service*, coded 15105152, 79 × 47mm
1 433MHz UHF receiver (RX1)
1 12V DC plugpack rated at 100mA
1 UB5 or UB3 case (see Part 2)
1 8-pin DIL IC socket
1 PCB mount DC socket with 2.1 or 2.5mm centre pin to suit plugpack plug (CON1)
6 PC stakes
1 170mm length of light-duty hook-up wire
1 20mm length of 1mm-diameter heatshrink tubing
2 10kΩ miniature horizontal mount trimpots (code 103) (VR1,VR2)

Semiconductors
1 PIC12F675/I-P microcontroller (programmed with 1510515B.hex (IC1)
1 78L05 5V regulator (REG1)
1 1N4004 1A diode (D3)

Capacitors
2 100μF 16V PC electrolytic
1 100nF MKT polyester

Resistors (0.25W, 1%)
1 1kΩ
1 100Ω

Extra parts For Version 1 (relays and mains remote control)
1 UHF remote controlled mains switch
1 UB3 box 130 × 68 × 44mm
2 SPST DIP 5V reed relays (Relay1,Relay2)
2 1N4148 diodes (D1,D2)
3 2-way pin headers
3 2-way pin header plugs
1 100Ω 0.25W 1% resistor
2 M3 × 9mm tapped spacers
4 M3 × 6mm tapped spacers
12 M3 × 6mm screws OR
6 M3 × 6mm screws AND
6 M3 × 6mm countersunk screws
120mm × 6-way rainbow/IDC cable

Extra parts For Version 2 (audible and visual indication)
1 UB5 box, 83 × 54 × 31mm
2 M3 × 9mm tapped spacers
4 M3 × 6mm screws
1 piezo transducer
1 green high intensity LED (LED1)
1 red high intensity LED (LED2)
1 1kΩ 0.25W 1% resistor

REG1's 5.5V output appears at pin 8 and is used to drive regulator REG2. The 5.5V rail from REG1 is also used as the supply for the set/reset pulse generator circuit based on MOSFETs Q2 and Q1.

REG2 is a low quiescent current and low drop-out regulator. Its low drop-out specification means we only need to provide 5.5V for the regulator to fully regulate to 5V. By contrast, most standard regulators require at least a 6.5V input to regulate to 5V.

Average current

The average current drawn from the 5V supply is around 550μA. However, the current drawn from the AA cell is much higher than this. That's because the AA cell has an output of just 1.25V and this is stepped up to 5.5V before being regulated to 5V. So you would expect the current drawn from the AA cell to be some 5.5/1.25 = 4.4 times higher, assuming that the TL499A regulator's step-up efficiency is 100% which, of course, it isn't.

At a more realistic 70% efficiency, the current would be expected to be 6.3 times higher. And that means that the calculated total average current drawn from the AA cell is 3.5mA.

In practice, we measured a current drain of close to 3mA in our prototype. That means that a 2000mAh AA NiMH cell would last for about 28 days without recharging. The solar panel we tested charged the cell at 20mA in mid-morning autumn sunlight and that is more than sufficient to maintain the cell's charge.

Diode D1 provides protection if the solar panel is connected with the wrong polarity, while D2 provide reverse polarity protection if the 1.25V cell is inserted in its holder the wrong way around.

Finally, resistor R1 is included to provide current limiting if a 9V or 12V mains plugpack is used instead of a solar panel to recharge the battery. This resistor is normally shorted out on the PCB since it is not required when a solar panel is used. However, the PCB track has a section that's easily cut if the resistor is required (see the construction details next month).

Receiver circuit

Fig.11 shows the receiver circuit details. It's based on the 433MHz receiver module, an 8-pin PIC12F675 microcontroller (IC1) and a 5V regulator (REG1). Also shown are the entry and exit LEDs, the piezo transducer and the alternative reed relays.

Microcontroller (IC1) monitors the data signal output from the UHF RX (receiver) module and acts when it receives a valid code. The arrival, departure and non-directional signal codes are all different, so that IC1 can discriminate between them.

IC1 also monitors trimpot VR1 at its GP4 input. This is the identity adjustment that is divided up into eight separate voltage bands. This voltage needs to match that set in the detector unit before any received signal is deemed valid.

Trimpot VR2 has its wiper monitored by IC1's GP2 input (pin 5). This trimpot sets the alert duration. Alternatively, it sets the time period between relay 1 closing and relay 2 closing (and thus the period for which a remote-controlled mains socket is powered on).

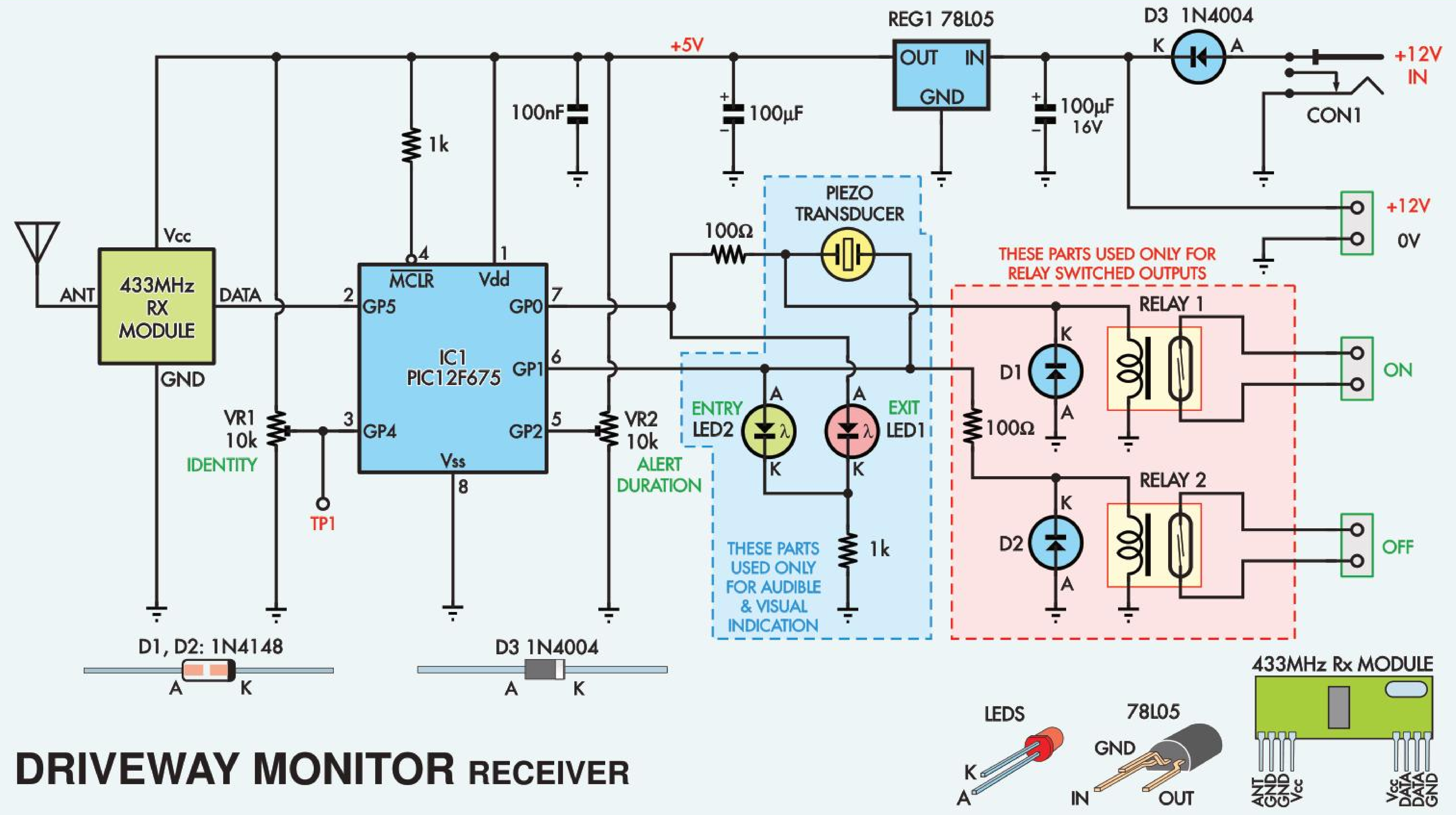
In operation, IC1 converts the voltages at GP4 and GP2 to 8-bit digital values. When a valid signal is received, its GP0 and GP1 outputs drive either the piezo transducer and one of the LEDs (LED1 or LED2) or relays Relay1 and Relay2. If used, the latter are wired across the 'On' and 'Off' switch contacts on the hand-held remote that's used with a remote-controlled mains socket.

Piezo transducer

The exit (or departure) tone from the piezo transducer is a 440Hz horn-type 'bip' lasting about 1s, followed by a 440Hz tone that smoothly increases to 6.8kHz over a period ranging from 1-5s (depending on the setting of VR2). LED1 (exit) also lights while the piezo sounds and stays lit for about 15s after the tone ceases.

By contrast, the entry (or arrival) tone starts with a 1s 440Hz horn 'bip' and is followed by a 6.8kHz tone that decreases to 440Hz (again adjustable from 1-5s). This makes it quite distinct from the exit sound, since the tone now decreases instead of increasing. In addition, the entry LED (LED2) lights during the tone and again stays lit for 15s after the tone ceases.

The non-directional tone is different yet again. In this case, there is a 1s


REG1 78L05
OUT
IN
GND
D3 1N4004
K
A
+5V
+12V IN
CON1
100nF
100µF
100µF 16V
1k
PIEZO TRANSDUCER
100Ω
+12V
0V
THESE PARTS USED ONLY FOR RELAY SWITCHED OUTPUTS
RELAY 1
RELAY 2
ON
OFF
D1
D2
100Ω
Vcc
ANT
433MHz RX MODULE
DATA
GND
MCLR
Vdd
GP5
GP0
IC1 PIC12F675
GP1
GP4
GP2
Vss
VR1 10k IDENTITY
TP1
VR2 10k ALERT DURATION
ENTRY LED2
EXIT LED1
1k
THESE PARTS USED ONLY FOR AUDIBLE & VISUAL INDICATION
D1, D2: 1N4148
D3 1N4004
LEDS
78L05
GND
IN
OUT
433MHz Rx MODULE
ANT GND GND Vcc
Vcc DATA DATA GND

DRIVEWAY MONITOR RECEIVER

Fig.11: the circuit diagram for the receiver circuit. The 433MHz RX (receiver) module picks up the signal from the detector unit and feeds its data output to PIC microcontroller IC1. When a valid code is received, IC1 drives a piezo transducer and activates either LED1 or LED2 to indicate vehicle entry or exit. Alternatively, the LEDs and piezo transducer can be omitted and reed relays fitted instead. These can then be wired across the buttons of a remote control unit, eg, for a remote-controlled mains socket or a wireless doorbell.

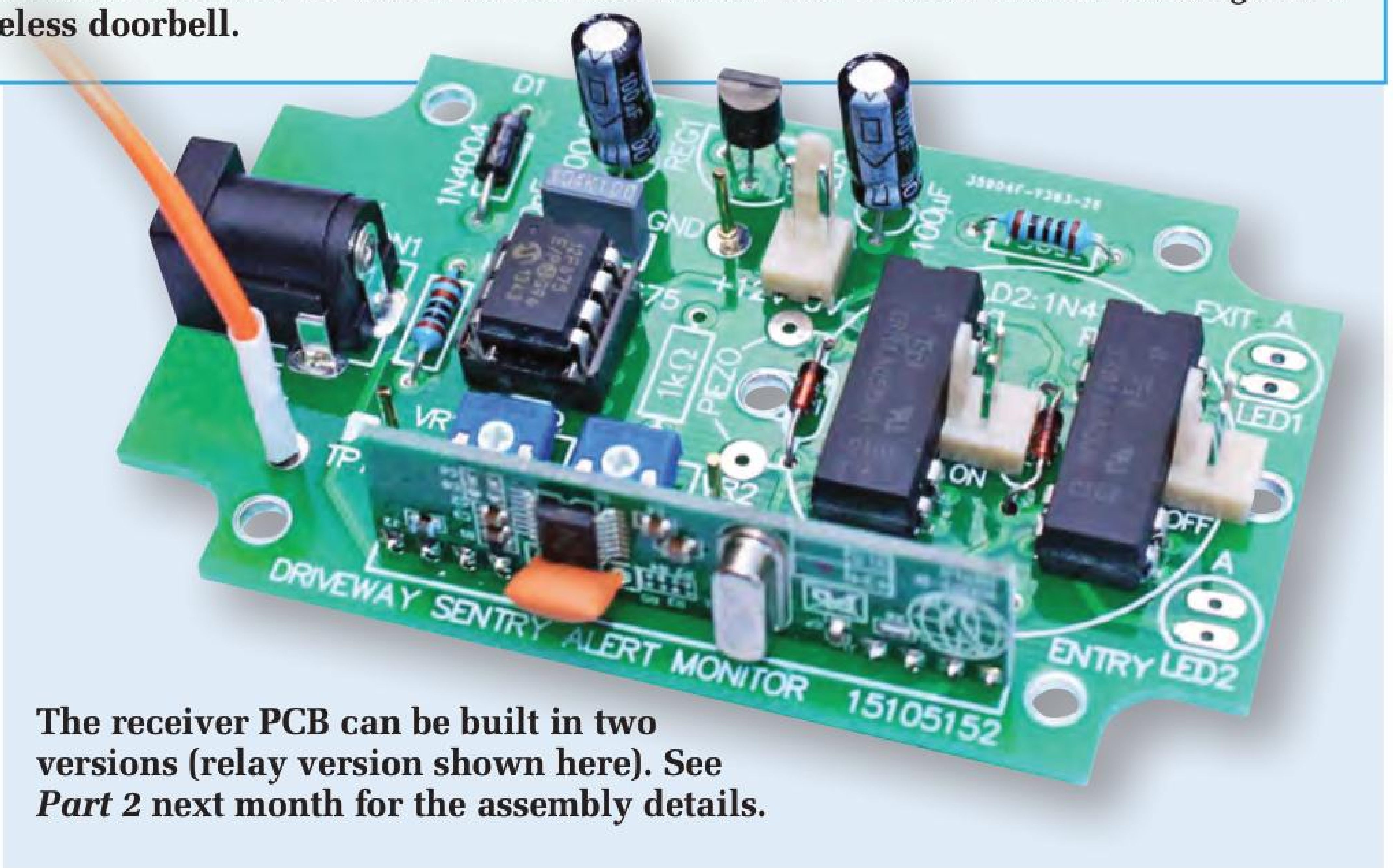
440Hz horn 'bip' followed by a further 440Hz 'bip' lasting from 1-5s. In addition, LED1 and LED2 both light and then flash alternately for 15s after the tone ceases.

Relay version

For the relay version, Relay1 is first switched on for 500ms, thereby allowing its closed contacts to activate the 'On' button on a UHF remote control (eg, for a mains socket). Then, after a preset period ranging from 20s to five minutes, as set by VR2, Relay2 is switched on for 500ms to activate the 'Off' button on the UHF remote.

Both relays are driven via 100Ω resistors, while diodes D1 and D2 clamp any switch-off voltage spikes produced by the relay coils. The 100Ω resistors are there to protect IC1's GP0 and GP1 outputs.

The program in IC1 automatically detects if the piezo transducer has been installed or if the relays have been installed instead. It does this by first making the GP1 pin an input and then switching GP0 high. If GP1 goes high immediately after switching GP0 high, then the piezo transducer is connected. That's because the piezo transducer's capacitance allows the voltage transition to be coupled through to GP1.


DRIVEWAY SENTRY ALERT MONITOR 15105152
ENTRY LED2
EXIT
LED1
ON
OFF
1N4004
D1
REG1
GND
PIEZO
VR
TP

The receiver PCB can be built in two versions (relay version shown here). See *Part 2* next month for the assembly details.

Conversely, if GP1 stays low, the software assumes that the relays are connected since Relay2's coil provides a low-resistance path to ground.

Power for the circuit is derived from a 12V DC plugpack, with diode D1 providing reverse polarity protection. REG1 then provides a regulated 5V supply for IC1 and the UHF RX module. The 100µF input and output bypass capacitors provide supply line filtering, while a 100nF capacitor provides additional decoupling for the supply going to the microcontroller.

That's all for this month. *Part 2* next month has the assembly details.

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POWERMASTER
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Intelligent Charger
for Nicad and NiMH Batteries
0
1 OFF
2 FL
3 ON
4 FL
5 FL
Standby
ON Cool Down
ON Soft Start
ON Fast Charge
OFF Trickle Charge
FL Error

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- Model racing cars
- Battery appliances
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Intelligent Charger for Nicad and NiMH Batteries

by PETER HAYLES

Cheap chargers supplied with the original equipment can – and often do – damage the battery. Proper chargers are usually expensive. This cheap and easy-to-build Nicad/NiMH Battery Charger is suitable for automatically charging a wide range of batteries.

This 'intelligent' charger, controlled by a microprocessor, was designed for high-current and rapid-charge charging applications such as are required for cordless power tools and model racing cars. These battery packs are expensive and can be difficult to purchase (it's usually cheaper to buy a new tool!). This charger uses the cell manufacturer's recommended charge method to safely and quickly charge batteries.

Introduction

Batteries for power tools and other electrical products range from 2.4V to 24V and usually consist of Sub-C size Nicad or NiMH cells. Properly treated, these battery packs should be good for hundreds of charges and potentially last many years.

The important part of that last statement is 'properly treated.' Batteries can be ruined by just one incorrect charge.

Unfortunately the battery packs are fairly expensive to replace, sometimes costing almost as much as the entire drill kit, if in fact you can purchase the batteries separately at all. Note that if you can solder, you can rebuild a pack with tagged cells – don't solder directly to batteries though!

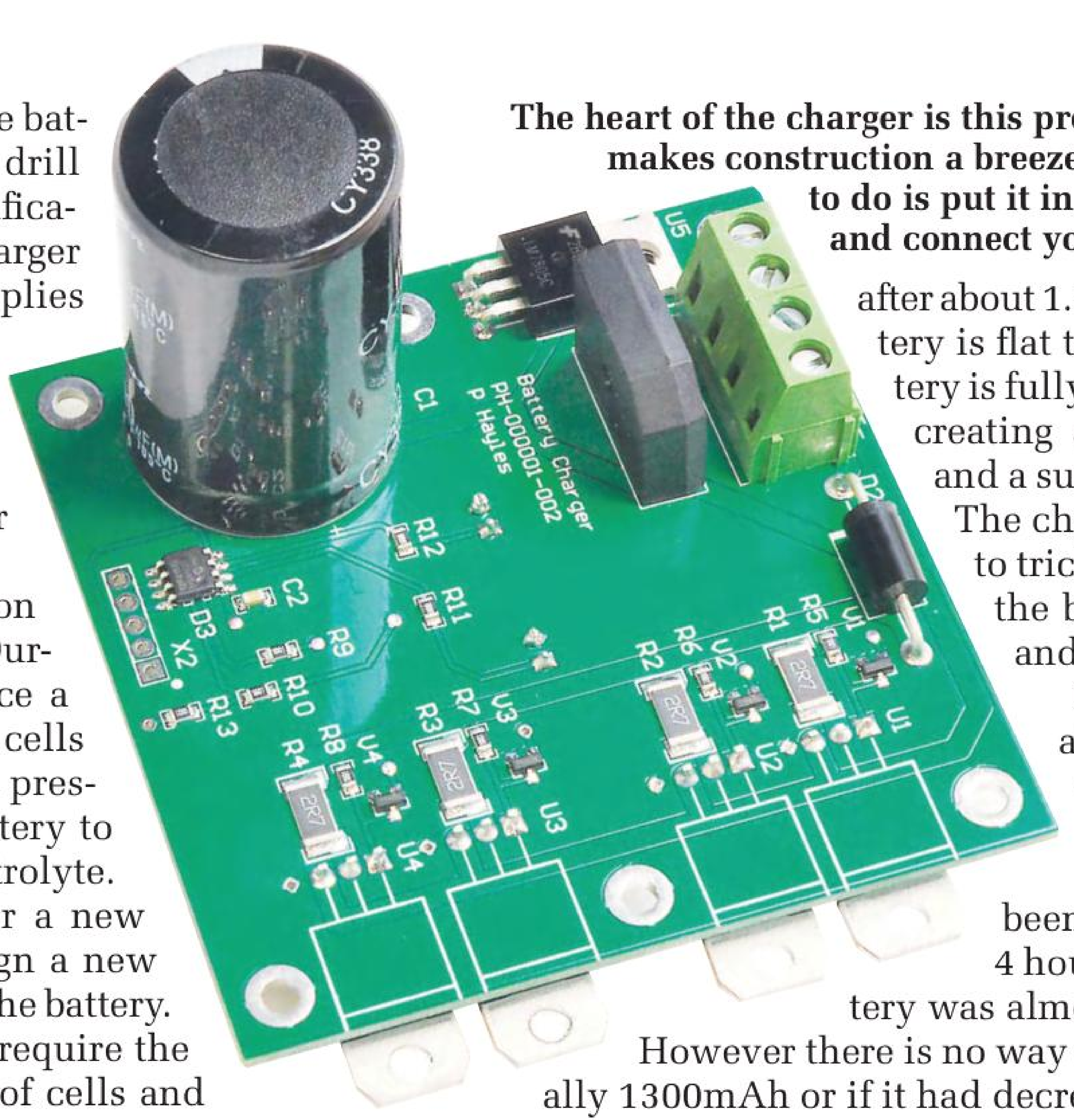
If you're really keen, you can even upgrade the battery to the latest Lithium cells (September 2014) but a special charger would be needed.

Recently, I found my two-year-old 9.6V cordless drill battery wouldn't perform to its rated capacity after charging.

I decided to repack the battery. In selecting replacement cells, I researched the manufacturer's specifications on charging and discovered that the battery charger that came with the drill didn't comply with these specifications. The supplied battery charger is a very simple device that applies constant current to the battery pack, with no cut-off, only a warning not to leave 'on charge' for more than 14 hours. As we will see, even this is a recipe for disaster!

There is no charge termination method used by the charger. During the recharging process, once a battery reach its full charge, the cells start to heat up and the internal pressure builds up, causing the battery to eventually rupture or vent electrolyte.

Having paid good money for a new battery pack, I decided to design a new charger that would not damage the battery. A better battery charger would require the charger to sense the condition of cells and charge accordingly. I soon realised that the simplest design would be a one-chip design. I selected a PIC controller as it was the smallest and cheapest device available at the time with a suitable analogue-to-digital converter.



The heart of the charger is this pre-assembled PCB which makes construction a breeze! Basically, all you have to do is put it in a box, connect power . . . and connect your battery to be charged.

Nicad/NiMH cell characteristics

Even if you don't want to build this charger, you still stand to gain something from this article by understanding how to get the most from your rechargeable batteries.

A cell is defined as a single vessel containing electrodes and electrolyte for generating current. A battery consists of two or more cells, usually connected in series to obtain a higher voltage.

Nicad/NiMH cells are nominally rated at 1.2V for design purposes, although they normally develop about 1.25V. Under full charge they require about 1.5V to 1.6V. They can supply very high current and display a remarkably flat discharge characteristic, ie, they maintain a relatively consistent 1.2V throughout discharge. The voltage then drops quite suddenly, and they are almost completely discharged at 0.8V. This is called the 'knee' characteristic because of the shape of the graph of voltage against time.

Rechargeable battery capacity is rated in mAh (milliampere-hours). The total capacity of a battery is defined as 'C', that is it can supply C mA for 1 hour, or 2C for 30 minutes.

Charge rates can vary:

- From trickle chargers (to keep the battery 'topped up') of 3.3% of C to 5% of C
- From a standard charger (a slow current charge) of 10% of C to 20% of C
- Or from a fast charger of 50% of C to 100% of C.
- Some ultra-fast chargers can go higher than 100% of C, but these are normally designed for a specific type of battery.

Slow charges are not meant to be continually applied, as they will eventually overcharge the battery. Since Nicad/NiMH batteries are about 66% efficient, the slow charge time is normally about 8-15 hours.

Fast charges, such as 100% of C, should be terminated after about 1.5 hours, providing the battery is flat to begin with. Once a battery is fully charged, it produces gas, creating a high internal pressure and a sudden rise in temperature. The charger should be switched to trickle charge at this point or the battery will begin to vent and release its electrolyte.

My old battery was rated at C=1300mAh and my old charger was rated at 400mA (30% of C) so the charger should have been switched off after about 4 hours, provided that the battery was almost flat to begin with.

However there is no way of knowing if C was actually 1300mAh or if it had decreased a bit and once the a battery starts to deteriorate, I suspect this becomes a vicious cycle and the battery deteriorates rapidly due to more and more overcharging.

The 'memory effect' myth

Possibly the biggest battery myth that exists – particularly for Nicad cells – is the 'memory effect'. The myth is that cells have to be completely discharged, otherwise they develop a sort of memory, and can only hold a partial charge from there on.

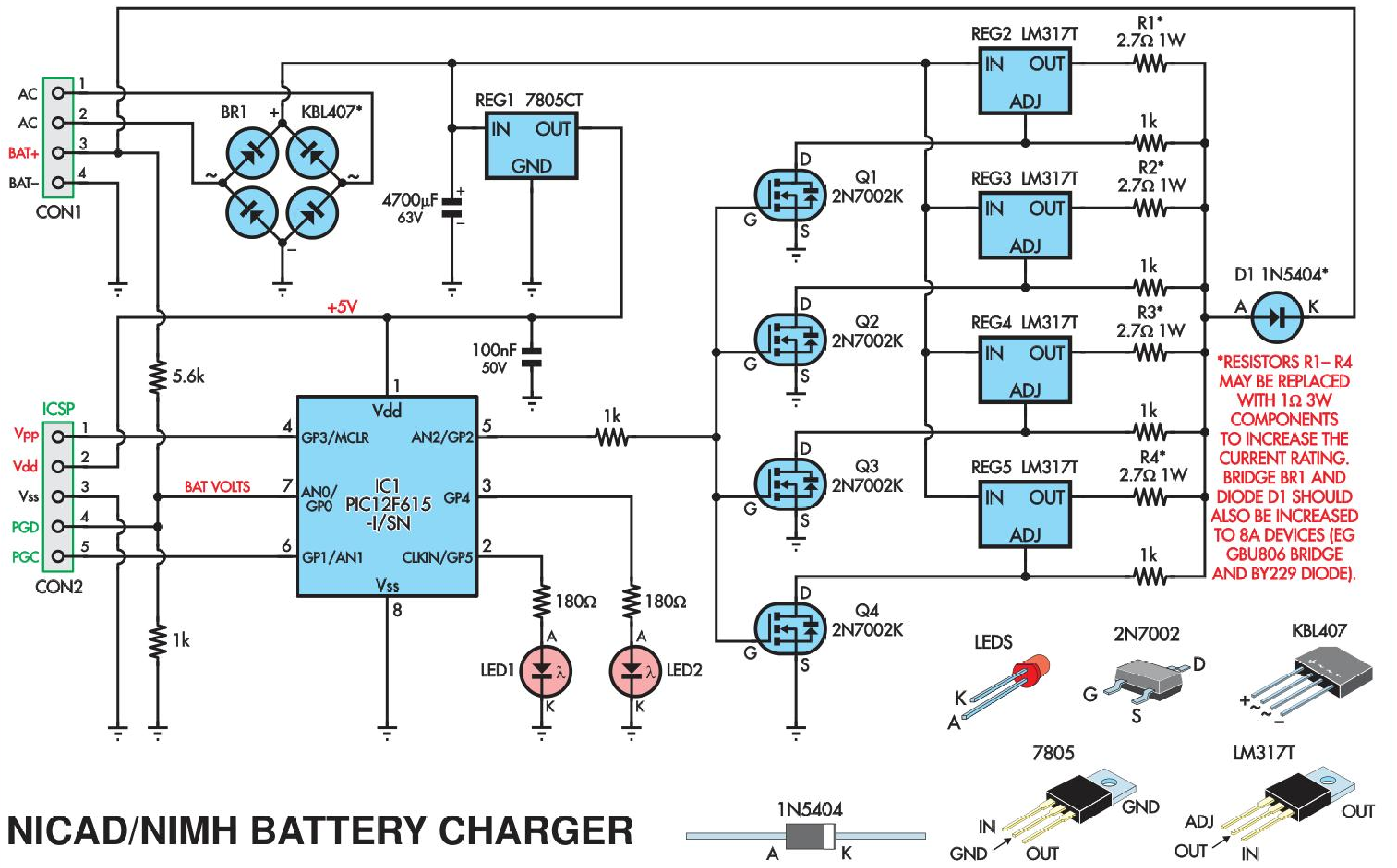
Like all good stories, this one has a grain of truth in it! The myth originated from the early days of satellites when they were using solar cells to charge batteries and because of the orbiting of the craft around the earth, the batteries were subjected to precise charge/discharge cycles many hundreds of times. The effect disappears when the battery cycle is suddenly varied, and it is extremely difficult to reproduce this effect even in a laboratory. In practice, the 'memory effect' is not a significant problem in home usage.

While it may be OK to discharge individual cells to 0V, it is certainly not recommended to discharge an entire battery of cells. When the battery is discharged below 0.8V per cell, one of the cells is inevitably weaker than the others, and goes to zero first. Then this cell begins to be charged in reverse.

This is easily observable on any battery pack. This creates a more common but less commonly known effect called 'voltage depression'. The battery performance is greatly affected by the weakest cell, as the cells are all in series.

One other thing – batteries don't like getting too hot or cold; they do not take a full charge and they actually self discharge (even under no load) much faster when over 40° or below 0°. They can build up internal heat when working and this can also cause temperatures inside to increase. Particularly avoid leaving cordless tools inside a hot car for this reason.

They also should be left to cool down for a while after discharge before placing them on charge. Nicad/NiMH batteries do self-discharge too, as a rule of thumb a battery will hold a full charge (with no load) for about a month or


AC
AC
BAT+
BAT–
1
2
3
4
CON1
BR1
KBL407*
+
~
~
–
REG1 7805CT
IN
OUT
GND
4700µF
63V
+
+5V
100nF
50V
5.6k
ICSP
Vpp
Vdd
Vss
PGD
PGC
1
2
3
4
5
CON2
1k
BAT VOLTS
1
4
7
6
5
3
2
8
Vdd
GP3/MCLR
AN2/GP2
AN0/GP0
IC1
PIC12F615
-I/SN
GP4
GP1/AN1
CLKIN/GP5
Vss
1k
180Ω
180Ω
A
LED1
LED2
K
D
G
S
Q1
2N7002K
Q2
2N7002K
Q3
2N7002K
Q4
2N7002K
REG2 LM317T
REG3 LM317T
REG4 LM317T
REG5 LM317T
IN
OUT
ADJ
R1*
2.7Ω 1W
R2*
2.7Ω 1W
R3*
2.7Ω 1W
R4*
2.7Ω 1W
1k
D1 1N5404*
A
K
LEDS
K
A
2N7002
D
G
S
KBL407
+
~
~
–
7805
IN
GND
OUT
GND
LM317T
ADJ
OUT
IN
OUT
1N5404
A
K

*RESISTORS R1– R4 MAY BE REPLACED WITH 1Ω 3W COMPONENTS TO INCREASE THE CURRENT RATING. BRIDGE BR1 AND DIODE D1 SHOULD ALSO BE INCREASED TO 8A DEVICES (EG GBU806 BRIDGE AND BY229 DIODE).

NICAD/NIMH BATTERY CHARGER

Four regulators share the load, which is the battery charging current. A single PIC microcontroller takes care of all the housekeeping, including monitoring the battery voltage to ensure it is not overcharged.

two, although when they get old or hot, they might only last a day, therefore:

- Don't discharge your battery before you recharge it,
- Don't flatten your battery below 0.8V per cell,
- Don't overcharge your battery beyond 100% of C
- Nicad/NiMH don't like to get too hot or too cold (0° to 40°C is ideal)
-

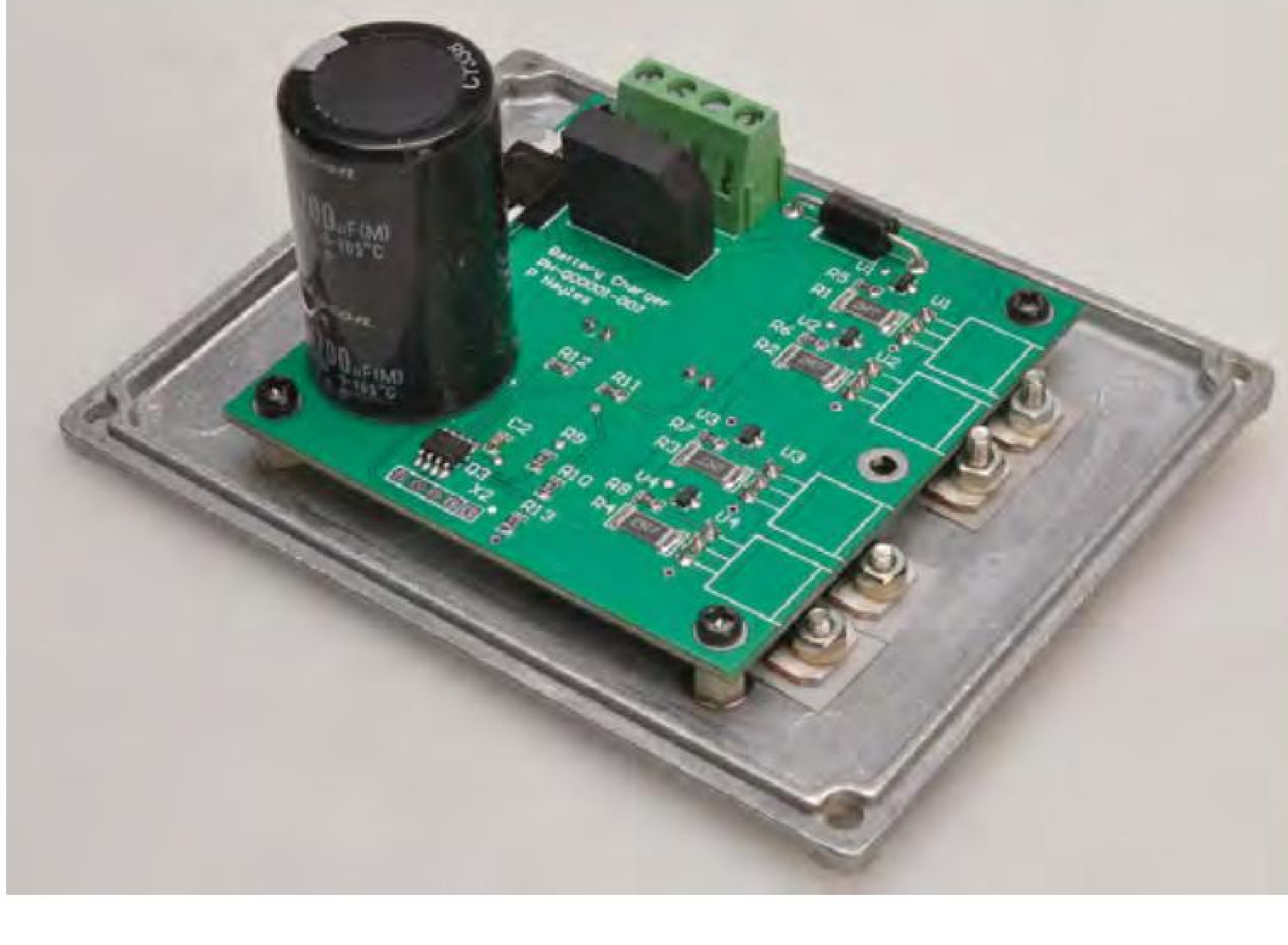
Nicad/NiMH charging

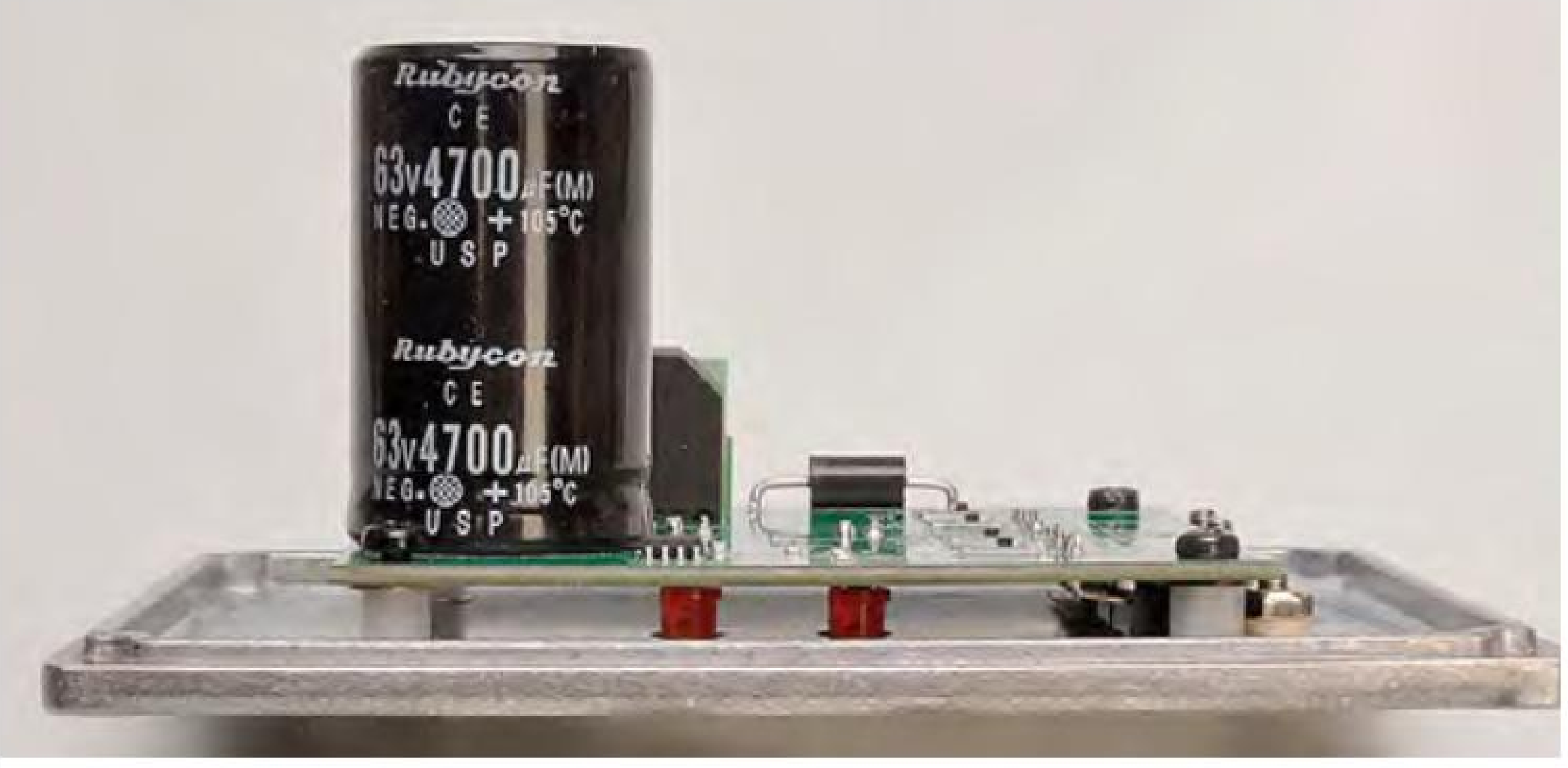
Common values for C for cordless tools and racing cars are in the range from 500mAh to 3000mAh (mostly sub C cells and AA cells). The first step is to determine what C is for your cells. Inspect the cells or contact the manufacturer to determine the cell part number.

In drills, the battery packs can often be easily disassembled. The value for C often forms some of the part number. For my new battery the value for C was 1700mAh. Note that the cell value for C is the same as the battery value for C.

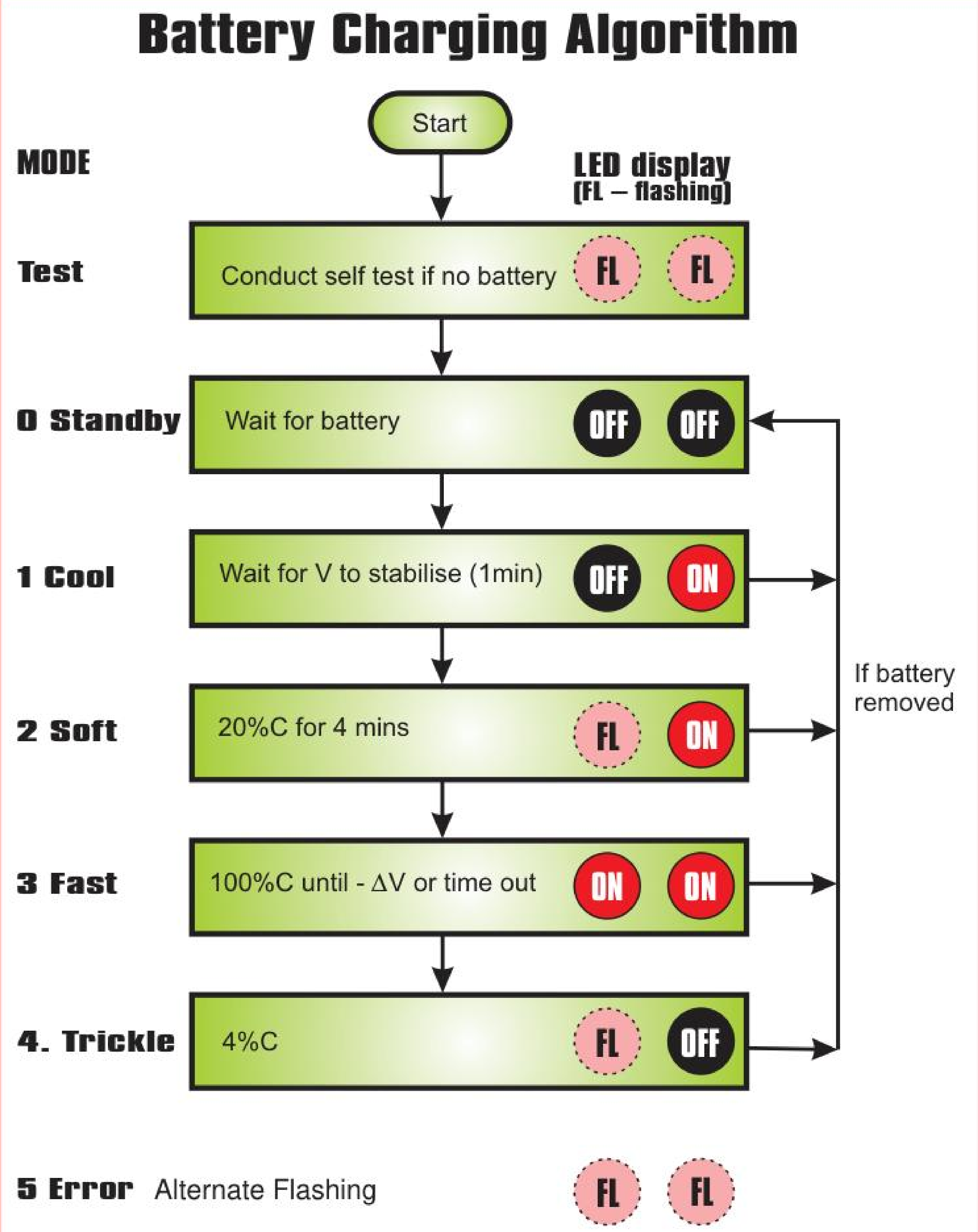
Usually, the charge time required is as fast as possible, between one and two hours. This does not harm the cells, in fact they are designed for it. My battery was capable of taking a fast charge of 100% of C, which equates to 1.7A (Some can take up to a 2C rate). Each of the four regulators must therefore supply around 450mA for a charge rate of 1C.

This value should be good for most readers, and it doesn't really matter if it is a bit less than 100% of C, because the charger will still detect a peak eventually anyway. However,

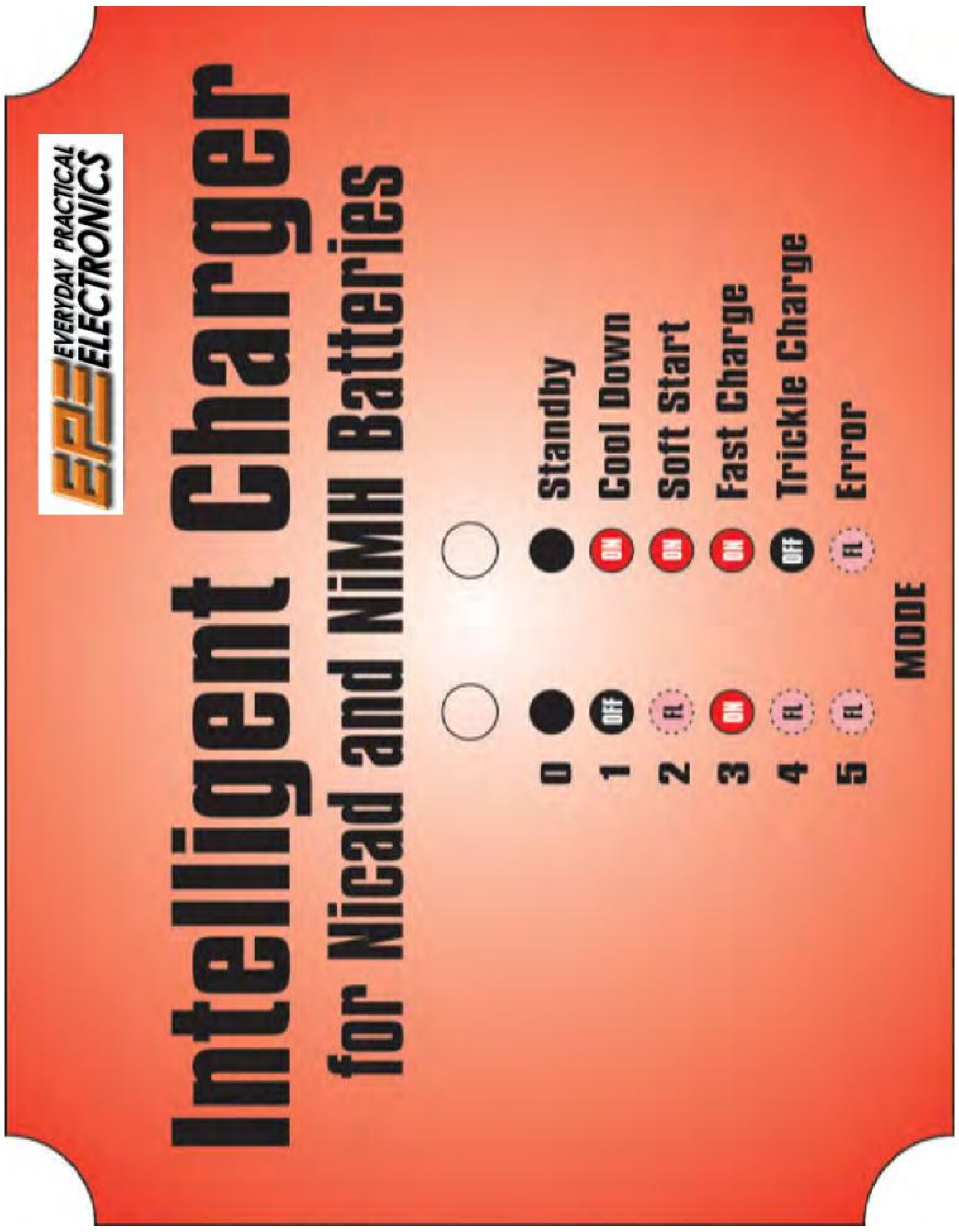




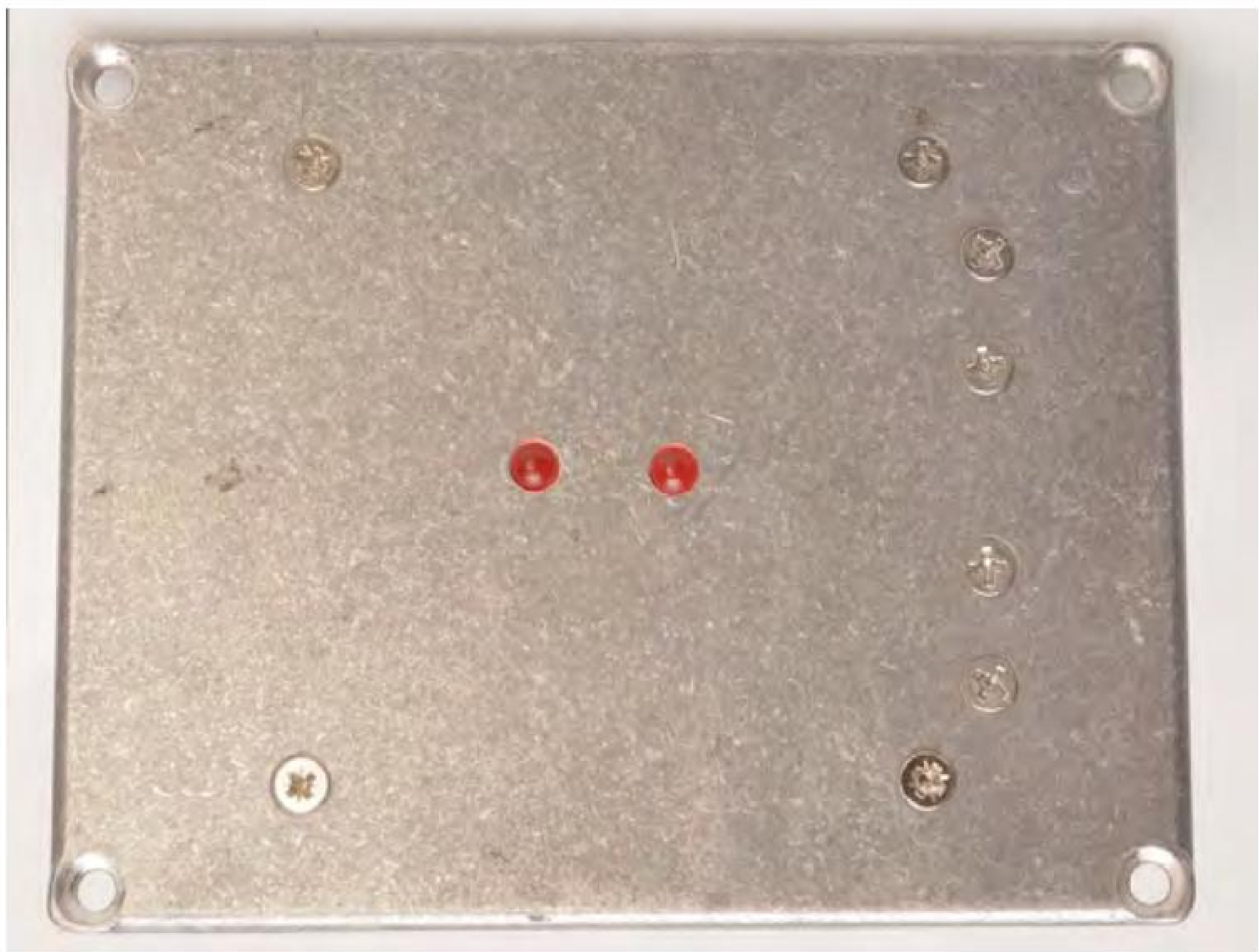
These two shots show how the PCB is secured to the diecast box lid – it actually mounts on small threaded stand-offs with countersunk head screws used from the top (lid) side. The four regulators must be fitted with insulating washers and bushes to prevent them shorting to the lid.


Battery Charging Algorithm
Start
MODE
LED display
(FL – flashing)
Test
Conduct self test if no battery
FL
FL
0 Standby
Wait for battery
OFF
OFF
1 Cool
Wait for V to stabilise (1min)
OFF
ON
2 Soft
20%C for 4 mins
FL
ON
3 Fast
100%C until - ΔV or time out
ON
ON
4. Trickle
4%C
FL
OFF
If battery removed
5 Error
Alternate Flashing
FL
FL

The algorithm flow-chart shows the steps the microcontroller goes through to charge the battery. LED codes are repeated on the front panel (see right)


EPE
EVERYDAY PRACTICAL ELECTRONICS
Intelligent Charger
for Nicad and NiMH Batteries
0
1
2
3
4
5
OFF
FL
ON
FL
FL
Standby
Cool Down
Soft Start
Fast Charge
Trickle Charge
Error
ON
ON
ON
OFF
FL
MODE

(Above) same-size label which can also be used as a template to get the LEDs emerging in the right place, as seen below (before the label was fitted).

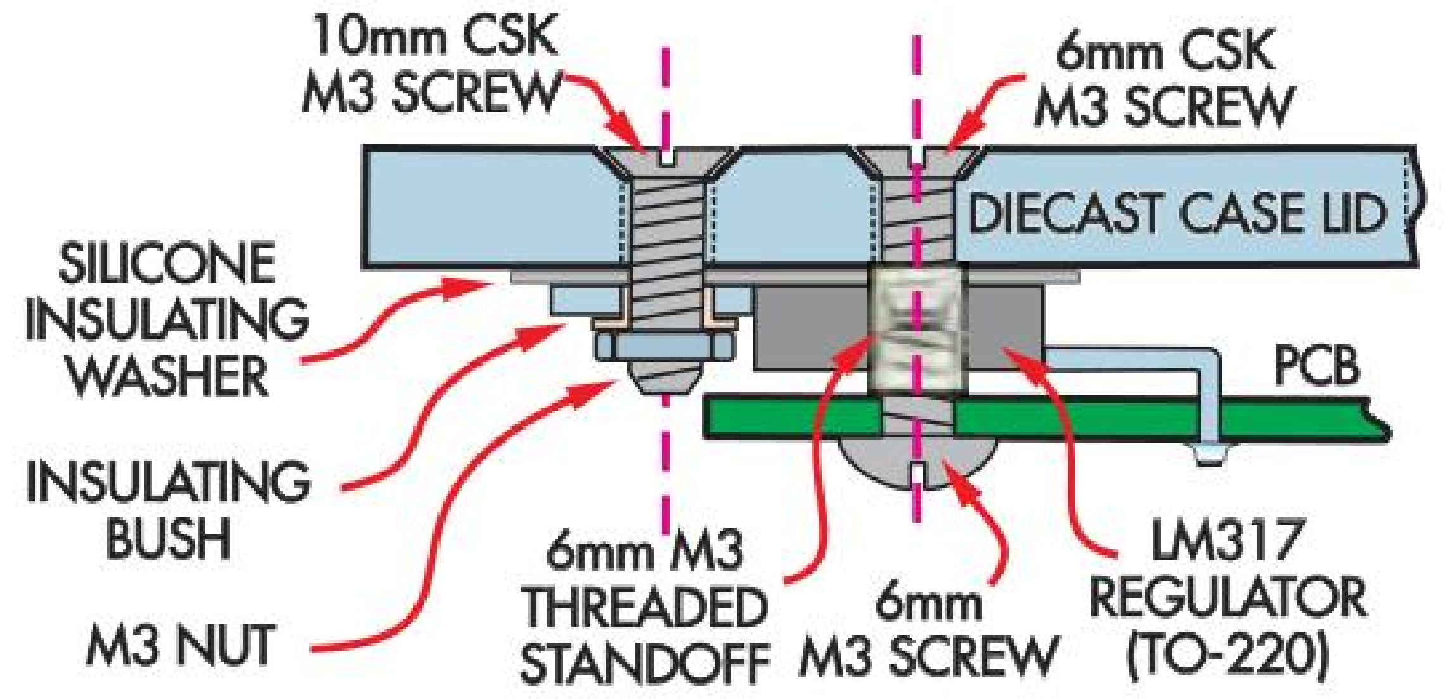


some readers will want to increase the maximum current, and this is described a bit later on.

There are two recommended methods of detecting charge termination, either using a temperature sensor in the battery pack or using a 'negative delta V' cutoff system. The temperature technique relies on detecting the sudden rise in battery temperature to shut off the charge. There is nothing wrong with doing this but battery packs do not always come with temperature sensors built in. Furthermore ones that do usually don't sense all of the cells. The negative delta V system relies on the electrical characteristic that the Nicad/NiMH battery voltage peaks and drops about 20mV per cell when fully charged. This charger in its basic configuration will detect a peak of 40mV (per battery) from 2V to 21.5V, thus will charge any battery pack in this range (ie, 2-20 cells or 2.4V to 24V).

Another point to consider is the requirement to let a battery cool down. If the battery has just come off discharge and is hot, it may take a minute or so for the charge to begin to start. Additionally, new batteries may show false peaks in the first four minutes of charge, as various cells synchronise their charge state. For this reason the charger starts with a slow 'soft start' charge for four minutes to allow the battery to cool and get past this point.

Normal operation of the charger is fairly straightforward: the charger is switched on and both LEDs will flash once for self test. The charger uses a threshold of 2V (open-circuit voltage) to recognise that a battery has been connected. The charger will progressively start and peak the battery. The battery can be left on trickle charge indefinitely.


10mm CSK M3 SCREW
6mm CSK M3 SCREW
DIECAST CASE LID
SILICONE INSULATING WASHER
PCB
INSULATING BUSH
6mm M3 THREADED STANDOFF
6mm M3 SCREW
LM317 REGULATOR (TO-220)
M3 NUT

Here's how the four regulators are mounted using insulating washers and bushes; also how the PCB mounts to the case lid via four threaded stand-offs and screws.

Powering the charger

The method of powering the charger depends on what you want to charge – that is, the voltage and current rating of the batteries.

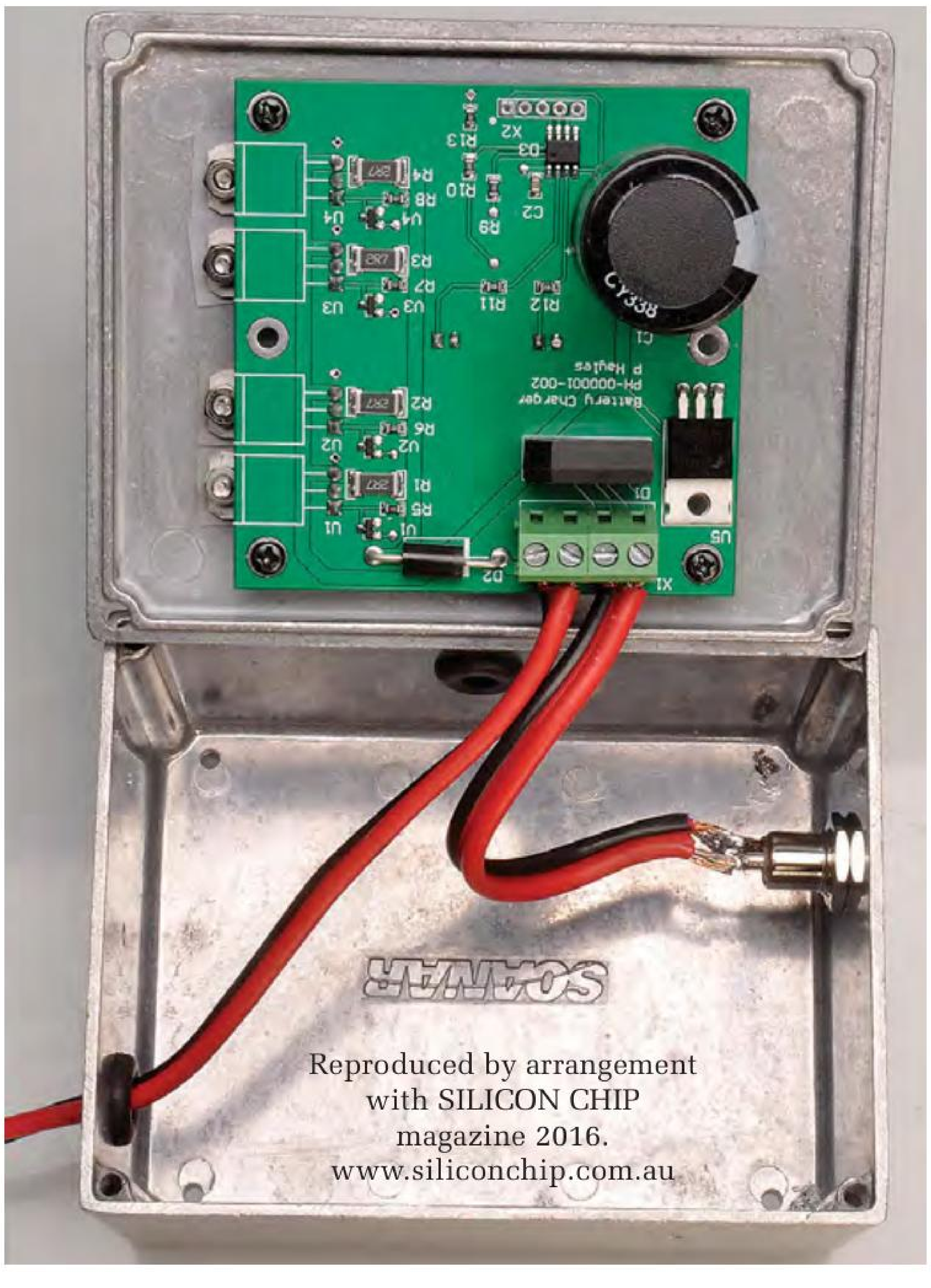
As specified, the charger is intended for low-voltage cordless power tools with batteries of, say, 9-18V. And as it has a bridge rectifier built in, you can power it with either AC or DC. Of course, the current rating of the transformer or DC supply needs to equal or exceed the required charging current.

For batteries up to 7.2V (six cells) a 12VDC or 9VAC supply rated at 2A or so would be ideal (as you can see from our photos, we used a perfectly good 12V/3A supply from a perfectly bad laptop PC!).

For higher voltage batteries, you'll need a higher-voltage supply – say 24VDC or 15-16VAC for 12-14V batteries (again, look at surplus laptop supplies – there are plenty around with 16-18V output at 3-4A) but if you want to charge a 24V battery, you're going to need something higher – say 30VDC or 24VAC.

It is strongly suggested that a 'plugpack' supply or transformer be used; these keep the 'bitey bits' out of harm's way, especially for beginners.

If you must (and you know what you are doing) a transformer could be used and mounted inside a (much larger) case with the PCB.



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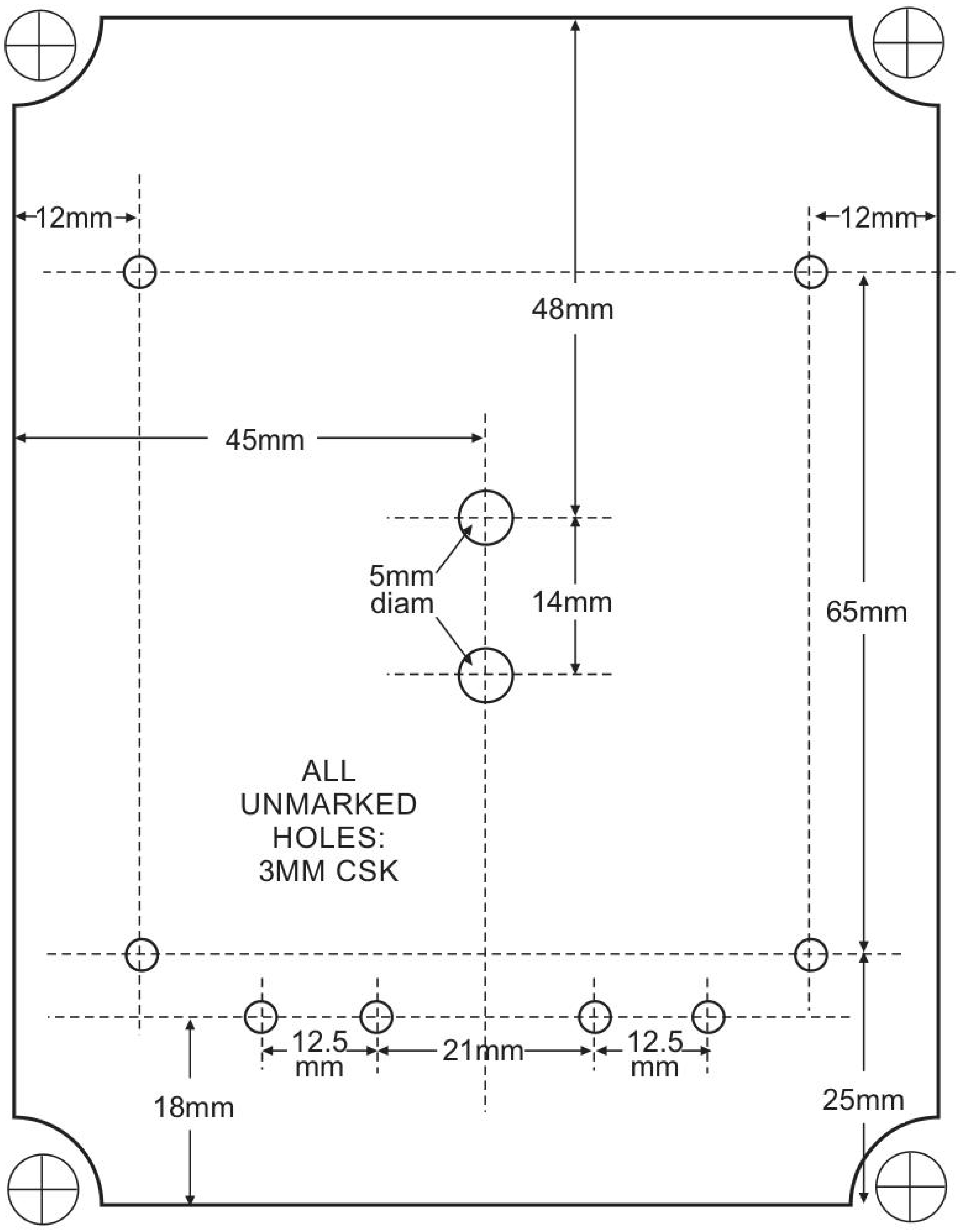
In this 'opened out' shot, the lid-mounted PCB is at the top with the output on the left and the socket for the AC or DC supply on the right.



Here's a template to help you drill out the diecast case. It is intended for a standard 117 × 92 × 55mm case.

Operation

A constant-current supply is generated by several parallel linear regulators and pulse-width-modulated by a PIC12F615-I/SN microcontroller. The microcontroller senses the battery voltage and internally uses an analogue-to-digital converter to read the battery voltage.

The microcontroller has its own 5V regulated supply (delivered by a 7805 regulator) and displays the current charging status on two LEDs.

Four LM317T regulators connected in parallel will each maintain 1.25V between their OUT pin and ADJ pin. A 2.7Ω SMD resistor in the output limits the current to a constant 1.8A, or about 450mA per regulator. These resistors also help to ensure that the load current is spread evenly between the regulators.

A power diode in series with the output makes sure that current can only flow in one direction; it will be reverse-biased and therefore stop current if a charged battery is connected with the circuit not powered.

A voltage divider, consisting of a 5.6kΩ and 1kΩ resistor monitor the battery voltage, while ensuring that even with a high-voltage battery (eg, 33V) the input to the PIC cannot exceed 5V (the input limit).

From this point, virtually all circuit operation is controlled by the PIC. It monitors battery connection and if one is present, waits for one minute for the voltage to stabilise (which could be required if the battery is hot from hard use). It then provides a 'soft' charge for four minutes, followed by a fast charge. The fast charge terminates when the microprocessor senses the 'delta V' point of battery charge or in worst case, if the charge time is exceeded. It

Increasing the charging current

As supplied, each regulator has a 2.7Ω SMD resistor in its output. As well as limiting the charging current to ~450mA per regulator (or 1.8A total), these resistors help to ensure that the load is shared equally between the regulators.

If you have a higher-rated battery (eg, ~5000mAh, which can handle higher charging currents), by lowering this to a 1Ω 3W SMD resistor (2512/6432 size), the total charging current will approach 5A.

The bridge rectifier (BR1) would need to be changed to, say, an 8A GBU806 (same pinout), as would D1 – a BY229 is also rated at 8A.

We haven't tried these changes, by the way, but the output current is well within the regulators' ratings.

The only rider on this is that dissipation will also increase, so simple heatsinking to the case lid might not be enough. At a minimum, we'd also add some heatsinking compound to ensure as much heat as possible is removed. An alternative might be to use a 'real' heatsink.

then enters a 'trickle' charge state which is intended to maintain the battery at full charge until it is used.

LEDs

Two LEDs, driven by the microcontroller, give a visual indication of which mode the charger is in. These modes, with LEDs on, off or flashing, are shown on the front panel of the charger.

Construction

Because the PCB is supplied already built and tested (no need to solder those pesky SMDs!) the only construction required is to put the charger in a suitably drilled diecast box and connect input and output wiring.

We used a diecast box not so much for its strength (though it certainly has that!) but because the diecast box provides heatsinking for the four LM317T regulators.

The only fiddly bit about this is that the drilling for these, the two status LEDs and the four PCB mounting screws must be pretty good! Use our diagram as a guide (or even a template if your photocopier is accurate).

We mounted the PCB upside-down in the case, so that it 'hangs' from the lid rather than mounts on the bottom. This is to allow the two status LEDs to poke through the front panel. While using the lid does not give quite the same heatsinking as using the box itself, it's more than adequate for the task.

All screws through the lid were countersunk so the label could be glued flat on the panel. There's not a lot of depth available in the case with the large electrolytic capacitor hanging down, so we used the shortest M3 countersunk screws we could find (6mm). These go into tapped 6mm stand-offs, with four more M3 screws (5mm pan or flat head, this time) securing the PCB to the stand-offs.

If you find (as we did) that the stand-offs aren't quite long enough to accommodate both screws, you could use 10mm types or place a 3mm inner diameter washer each side of the stand-offs to make them just that little bit longer.

The four LM317 regulators need to be insulated on the diecast box in the usual way – our diagram shows how the flat insulating washers and the round insulating bushes (one set per regulator) ensure there is no shorting to the case.

Input and output leads depend a lot on your application. We used a surplus laptop supply, so we simply drilled a hole in one end of the box and used a panel-mounting DC power socket which matched that on the supply.

The output merely goes to some heavy-duty polarised figure-8 cable with spade connectors on the far end (again, because these suited our application). You might prefer to use crocodile clips or some other plug/socket arrangement. That's up to you.

Input and output leads all screw into the same PCB-mounted terminal block. The PCB is clearly labeled so you shouldn't be able to mix them up (did someone mention Murphy?).

And that's it! As we mentioned earlier, the PCB is tested when assembled so it should work straight away.

Wheredyageddit?

The pre-assembled and tested PH-00001 PCB comes from Shapely Electronics Design (www.shapely.asia) and sells for $50.00 inc GST, +P&H.

All other components – the diecast box, DC power socket, standoffs, silicone insulators and grommets, etc, are commonly available from electronics retailers.

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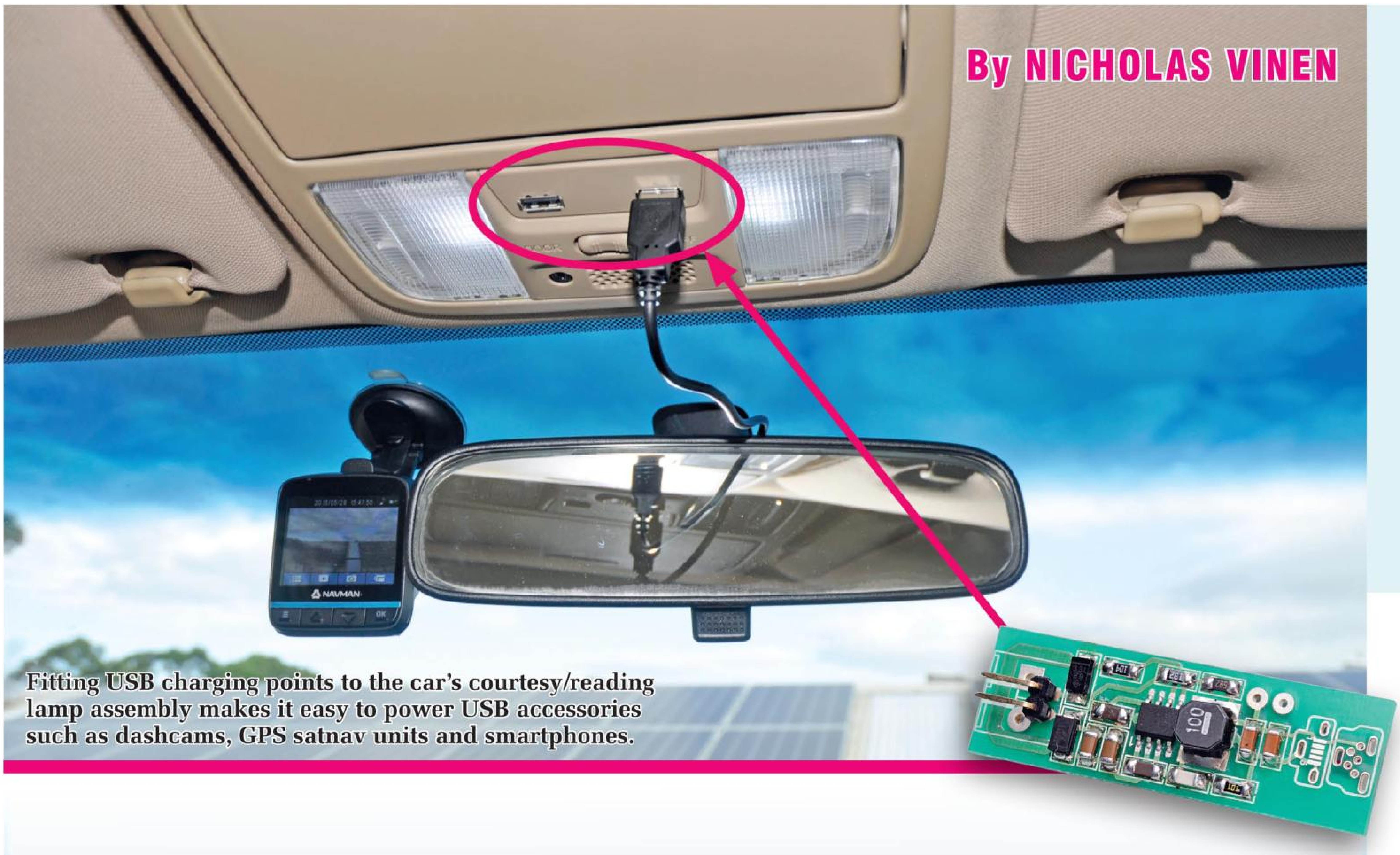


Fitting USB charging points to the car's courtesy/reading lamp assembly makes it easy to power USB accessories such as dashcams, GPS satnav units and smartphones.

Install USB charging points in your car

By NICHOLAS VINEN

New cars often have more than one USB socket for charging devices, but older cars have none. This tiny PCB will let you add one or two USB sockets and the total charge current can be up to 2.5A, more than enough for phones, satnavs or dash cameras.

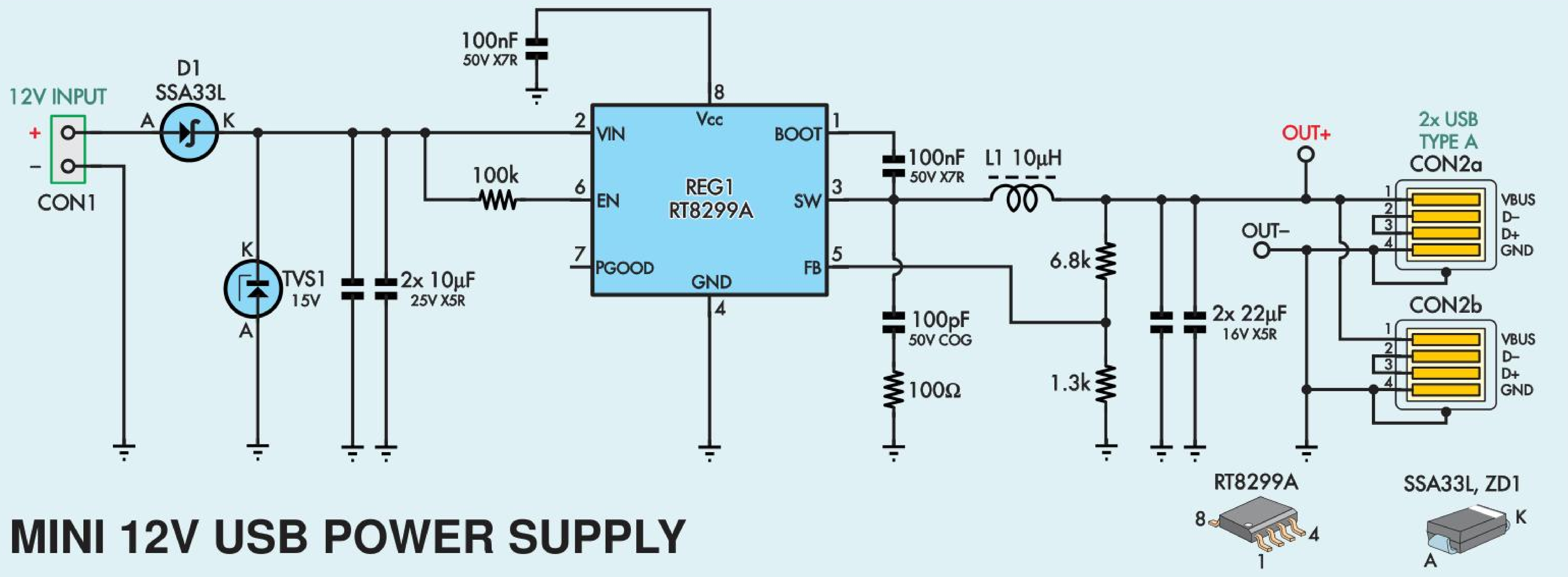
EVEN IF YOUR CAR has a USB socket, it's probably not in the ideal spot. Many people want to use a dash camera or a GPS satnav and in each case this means an untidy USB cord dangling over the dash to the closest 12V accessory socket. Ideally though, you need a USB socket close to the accessory you are using, either somewhere on the instrument panel or close to the rear vision mirror, possibly built into the housing for the sunglasses holder.

Another point is that people want a USB socket in their car which is powered all the time, even when the car is locked up at night. This would allow you to charge a phone at any time – very handy if your area has no power for days at a time or you are on a camping trip.

So that's the main reason for this little project. It lets you tap into the car's 12V courtesy light bus because that is always powered, ready to turn on the interior lamps whenever you open a door.

The tiny PCB is small enough to be tucked up inside a typical reading lamp assembly located just behind the rear vision mirror. One or two USB sockets can then be fitted in cutouts made in this assembly, so that the accessories can be plugged in using standard USB cables.

But that's just the start of what this tiny PCB can be used for. There are


12V INPUT
+
–
CON1
D1
SSA33L
A
K
TVS1
15V
2x 10µF
25V X5R
100nF
50V X7R
100k
2
VIN
6
EN
7
PGOOD
8
Vcc
REG1
RT8299A
GND
4
BOOT
1
SW
3
FB
5
100nF
50V X7R
L1 10µH
100pF
50V C0G
100Ω
6.8k
1.3k
2x 22µF
16V X5R
OUT+
OUT–
2x USB
TYPE A
CON2a
CON2b
VBUS
D–
D+
GND
RT8299A
8
4
1
SSA33L, ZD1
K
A

MINI 12V USB POWER SUPPLY

Fig.1: the circuit is based on an RT8299A switchmode step-down regulator (REG1). TVS1 protects the regulator from transient voltage spikes, while diode D1 provides reverse polarity protection. REG1 feeds two type-A USB sockets.

many situations where you may want to efficiently derive 5V or 3.3V from a higher voltage at an amp or two.

It uses just a handful of parts costing only a few pounds and a tiny (and thus cheap) PCB. The parts are almost all SMDs, but most are easy to solder and you could probably build it in under an hour.

Circuit description

The circuit diagram is shown in Fig.1. It's based on an RT8299A switchmode regulator IC from Richtek, a Taiwanese-based semiconductor manufacturer founded in 1998. They have released many low-cost, high-performance integrated switchmode regulator ICs and this is one of them – the data sheet is dated January 2014.

The RT8299A is a 500kHz synchronous step-down regulator. It icludes an oscillator, ramp generator, voltage reference, under-voltage lockout circuit, error amplifier, compensation components, comparator, flipflop, MOSFET drivers, MOSFETs and a current sense shunt/amplifier. Fig.2 shows its internal block diagram, taken from the data sheet.

Before we get into the details of its operation, let's have a quick look at how a 'buck' or step-down switching regulator works. Fig.3 shows the general concept.

Switch S1 is rapidly toggled and while we're showing it as a mechanical switch it will normally be a MOSFET. While S1 is closed, current flows from the V_{IN} + terminal, through S1, inductor L1 and into the load, while simultaneously charging up output filter capacitor C1.

Note that when S1 initially closes, very little current flows as inductor L1 initially presents a high impedance. The current then ramps up in a linear fashion and builds up L1's magnetic field.

When S1 opens, L1's magnetic field begins to collapse and the presence of the field means that current continues

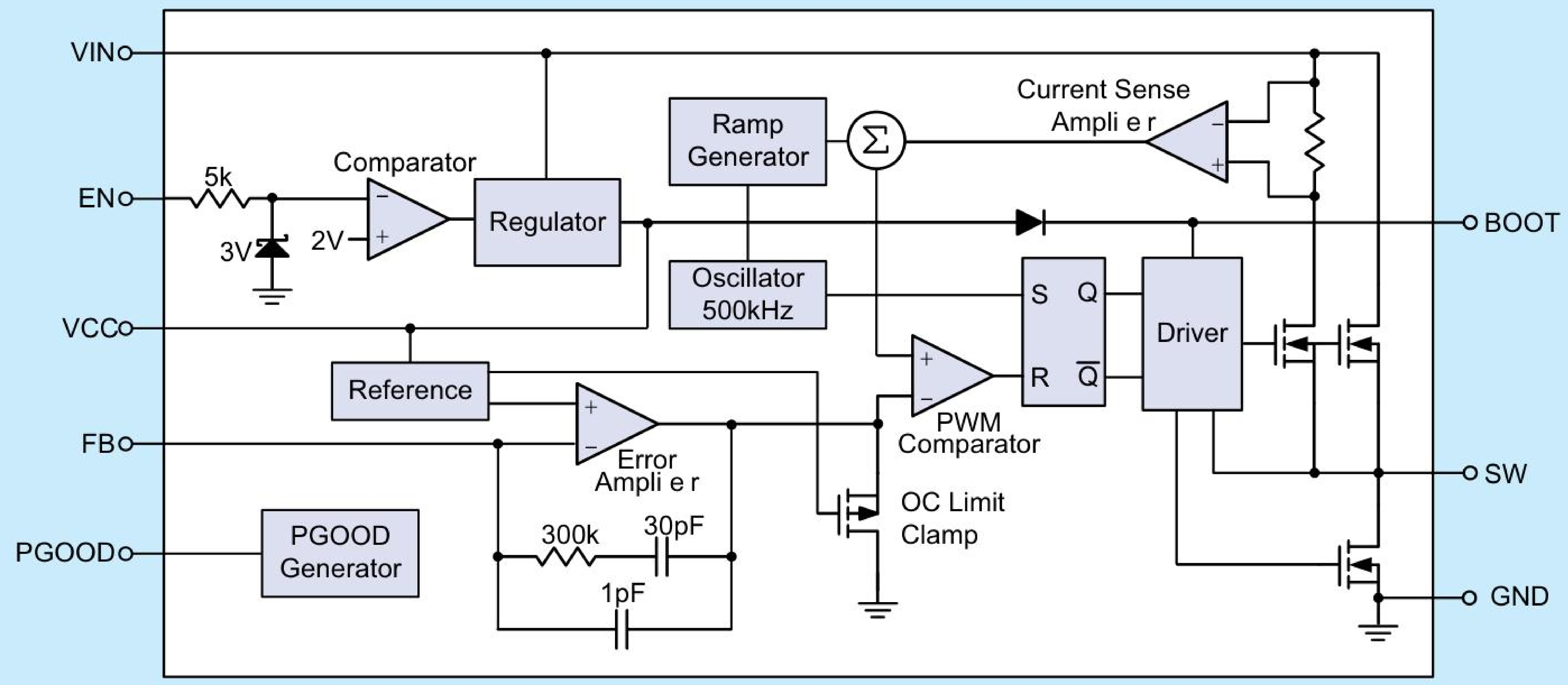

VIN
EN
VCC
FB
PGOOD
5k
3V
2V
Comparator
Regulator
Reference
PGOOD
Generator
Ramp
Generator
Oscillator
500kHz
Σ
Current Sense
Ampli e r
Error
Ampli e r
300k
30pF
1pF
PWM
Comparator
OC Limit
Clamp
S
Q
R
Q
Driver
BOOT
SW
GND

Fig.2: block diagram of the RT8299A switchmode regulator. It incorporates an oscillator, a ramp generator, voltage reference, under-voltage lockout circuit, error amplifier, comparator, flipflop, MOSFET drivers, various MOSFETs and a current sense shunt/amplifier

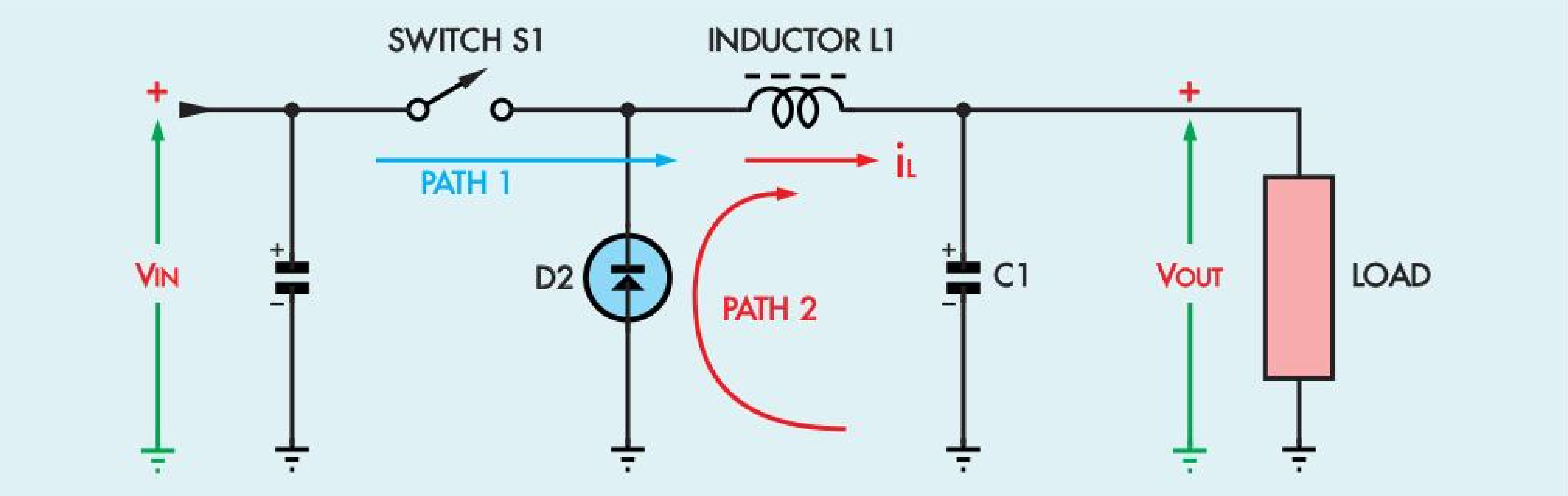


Fig.3: basic scheme for a switchmode buck converter. Voltage regulation is achieved by rapidly switching S1 and varying its duty cycle. The current flows via path 1 when S1 is closed and path 2 when it is open. In a practical circuit, S1 is replaced by a switching transistor or a MOSFET.

to flow into the load. This current must come from ground, via diode D2 (labelled PATH 2). The current through L1 falls linearly as its magnetic field discharges and similarly, the voltage across C1 drops as this capacitor helps to supply some of the load current.

S1 then closes again and the process repeats. The end result is that, depending on the switching duty cycle (ie, the proportion of the time that S1 is on), the voltage at V_{OUT} is proportionally lower than that of V_{IN} but depending on efficiency, the power drawn from V_{IN} is similar to that delivered to V_{OUT}, despite the different voltages. Thus, a switchmode regulator is usually much more efficient than a linear regulator.

Synchronous regulation

Of course, no circuit is 100% efficient so the output power will be less than the input power. Ideally, we want to minimise this power loss. There are several sources of inefficiency in a buck regulator circuit. One is the DC resistance of the inductor, which typically consists of many turns of wire and like any other resistor, energy is lost as current flows through it. Similarly, at the sort of switching frequencies typically used to keep the output ripple voltage manageable, there can be some core loss in the inductor too.

Another major source of inefficiency is the forward voltage of diode D2. Since D2 conducts more of the time at lower duty cycles, which are required when the output voltage is much lower than the input voltage, this loss can be quite significant under typical conditions. Usually a Schottky diode is used as these have a lower forward voltage – however, the loss due to D2 can still be significant.

The RT8299A IC addresses both of these major inefficiencies. First, its relatively high 500kHz switching frequency means that only a low value is required for L1. In fact, the recommended value is just 2.2μH. This means fewer turns of wire, so the wire can be both thicker and shorter and thus the resistive losses are low.

Then there is the fact that it is a 'synchronous' regulator. This means that diode D2 is replaced with a second switching element (let's call it S2) and this is driven synchronously with S1, ie, when S1 turns off, S2 immediately switches on. In the case of the RT8299A, S2 is another internal MOSFET.

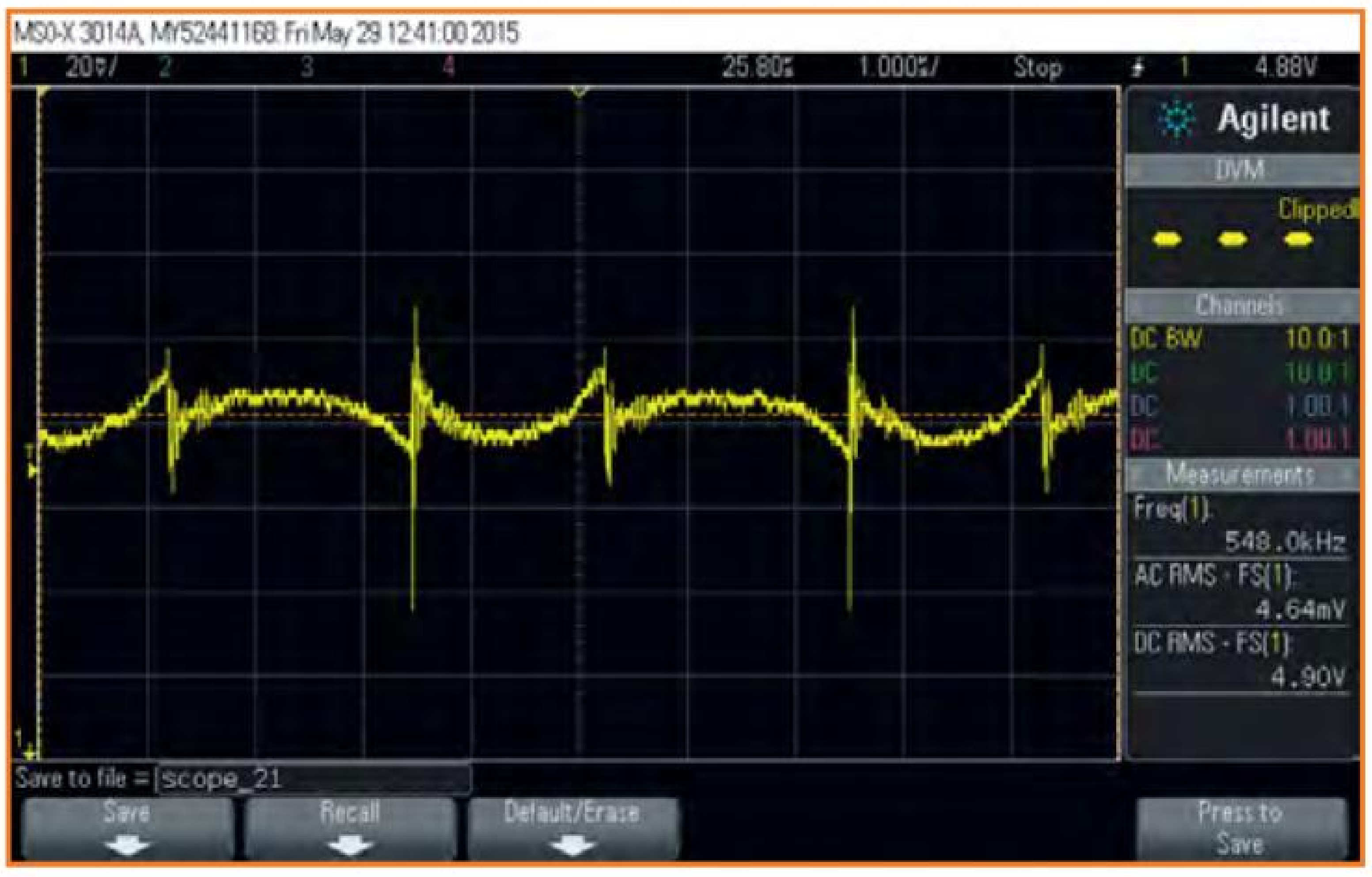
The advantage is that rather than the fixed voltage loss of a diode at high current (eg, 1V for a standard PN silicon diode or 0.5V for a Schottky diode), there is only the typical I^2R MOSFET loss. The RT8299A's internal MOSFETs have a typical on-resistance of 0.1Ω so at 2.5A, the voltage loss is similar to that of a 3A Schottky diode (ie, around 0.5V).

Most importantly, when the output current is lower, the I^2R loss is significantly less. For example, when it's delivering 1A, the I^2R loss will be well under 0.1V (as the duty cycle of S2 is less than 100%). The internal low-side switch also means one less external component is required and PCB space is saved.

The result of all this is that the efficiency is very good, up to 95% – see Fig.6. This means that even if you're drawing the maximum specified current from the board, it will barely even get warm. Which is good if you're going to tuck it away into a small space.

Back to the circuit

Now refer again to the full circuit of Fig.1. The operation of REG1 with


MSO-X 3014A, MY52441168: Fri May 29 12:41:00 2015

Freq(1): 548.0kHz
AC RMS - FS(1): 4.64mV
DC RMS - FS(1): 4.90V

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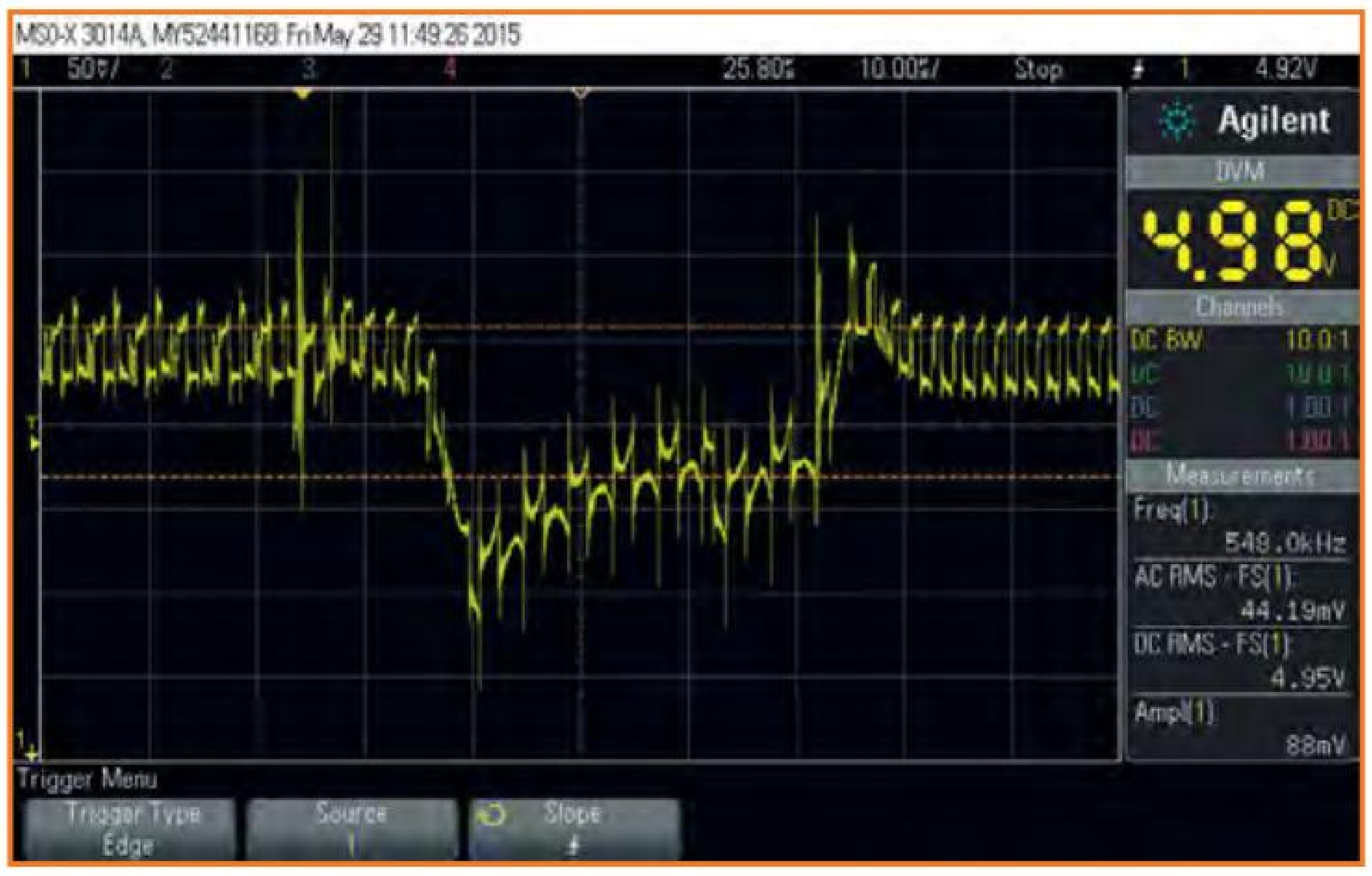
Fig.4: expanded view of the output voltage with a 3.9Ω load (1.25A). The amplitude of the ripple and the size of the switching spikes are exaggerated by the lead inductance of the scope probe. As you can see, the output is close to 5V (4.9V) and the ripple voltage is very low at less than 5mV RMS with a frequency of 548kHz.


MSO-X 3014A, MY52441168: Fri May 29 11:49:26 2015

DVM: 4.98V DC

Freq(1): 548.0kHz
AC RMS - FS(1): 44.19mV
DC RMS - FS(1): 4.95V
Ampl(1): 88mV

Trigger Type: Edge
Source: 1

Fig.5: regulator output voltage with the load switching rapidly between 22Ω (220mA) and 3.3Ω (1.5A). As you can see, the load regulation is better than 75mV and recovery is quick (timebase is 10μs/div). Note that the regulator is operating in discontinuous mode before the load step.

Features and Specifications

Wide input voltage range: 4-16V

High efficiency: typically >90%, 0.5-2A

Output voltage range: 0.8-15V (must be at least 2V below input)

Output current: up to 2.5A

Quiescent current: approximately 1mA

Output ripple and noise: typically <5mV RMS @ 1.2A (see Fig.4)

Load regulation: ~150mV/A, 0-250mA; ~75mV/A, 250-2500mA

Line regulation: <1mV/V

Transient response: output stabilises within ~20µs for a ±1.2A load step (see Fig.5)

Other features: no heatsinking necessary, soft start, short circuit protection, over-current protection, overheating protection, under-voltage lockout

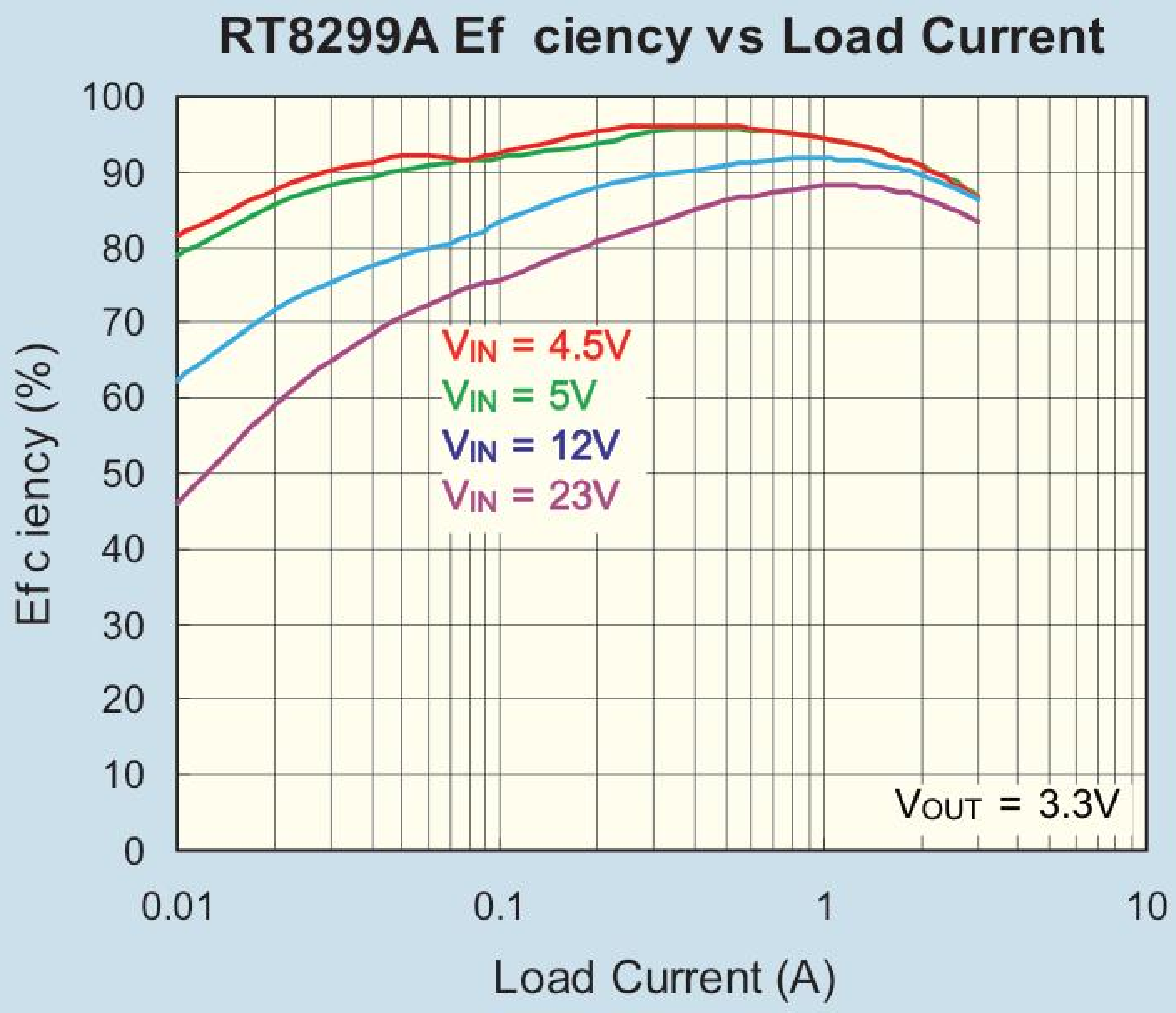


Fig.6: the efficiency of the circuit is very good – up to 95% and above 85% for input voltages up to 12V and load currents greater than 150mA.

respect to L1 was described above. Two paralleled 22µF SMD multi-layer ceramic capacitors are used as the output filter; this combination has very low ESR (equivalent series resistance), keeping the output ripple voltage very low. Similarly, two 10µF ceramic capacitors are paralleled for input bypassing, to ensure that REG1 has a stable supply voltage.

The 100pF capacitor and 100Ω resistor in series are a snubber from the switch node (pin 3 of REG1) to ground. This reduces the voltage slew rate at this pin when REG1's internal MOSFETs are being switched, reducing emitted radiation (ie, EMI).

A transient voltage suppressor (TVS1) protects REG1 from brief high-voltage spikes which may occur on a vehicle 12V bus due to load dumps and so on. REG1 can withstand around 26V (normal operating maximum 24V) so TVS1 was chosen as it will clamp REG1's supply to below 24V even if it has to dissipate up to 400W for around 10ms (ie, 16A). Its leakage current at normal automotive supply voltages (12-15V) is minimal.

D1 provides reverse polarity protection, should the board be wired backwards. It's a 3A Schottky diode so will have only a small effect on efficiency, with a forward voltage of less than 0.5V under typical conditions.

There are two 100nF capacitors connected to REG1. One is from the switch node (pin 3) to one labelled 'BOOT' (pin 1). This is charged up to 5V when pin 3 is low by REG1's internal diode and then shoots up to V_{IN} + 5V when the SW pin goes high. REG1 uses this as a gate drive voltage source for its internal upper MOSFET.

The other 100nF capacitor, at pin 8 (V_{CC}), is used to filter REG1's internal 5V rail which is used for various purposes. It's derived from V_{IN} within REG1 via linear regulator circuitry.

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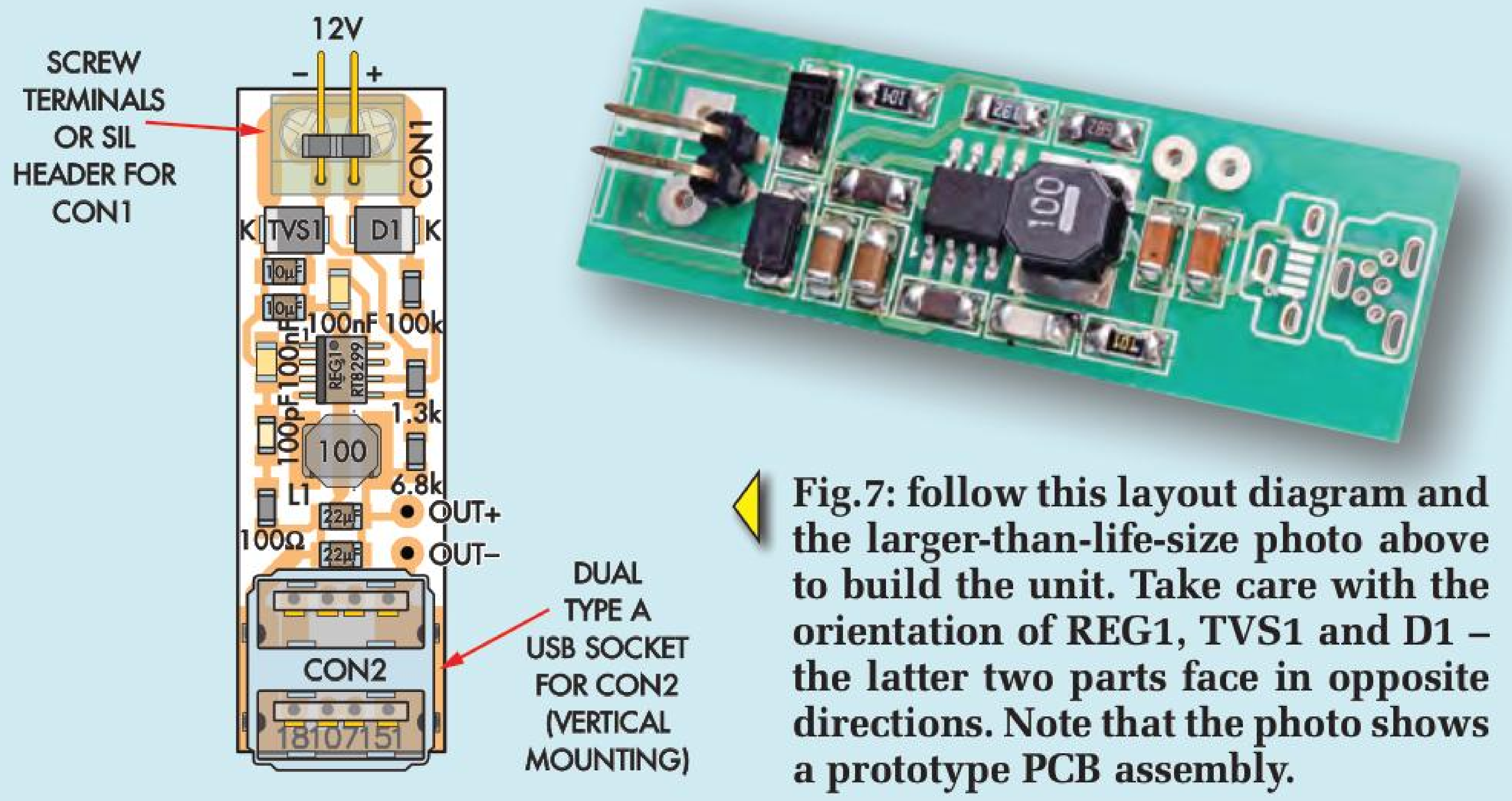


Fig.7: follow this layout diagram and the larger-than-life-size photo above to build the unit. Take care with the orientation of REG1, TVS1 and D1 – the latter two parts face in opposite directions. Note that the photo shows a prototype PCB assembly.

Feedback

The feedback voltage to pin 5 of REG1 comes from a simple resistive divider comprising 6.8kΩ and 1.3kΩ resistors across the output. REG1 attempts to maintain this feedback voltage at 0.8V and since the division ratio is 6.8kΩ ÷ 1.3kΩ + 1 = 6.23, this gives an output voltage of 0.8V × 6.23 = 4.985V.

In practice, due to various component tolerances, it will be in the range of 4.9-5.1V.

If you want a different output voltage, change the 6.8kΩ resistor. You calculate the new value in kilohms as: (V_{OUT} x 1.625) – 1.3 and pick the nearest value. For example, 3.9kΩ will give an output close to 3.3V (actually 3.2V). In this case, USB connector(s) would not be fitted and the board would drive some other circuitry.

The 100kΩ resistor from pin 6 (EN) to pin 2 (V_{IN}) causes the regulator to switch on as soon as power is applied.

Output connectors

As shown in the circuit, two USB output connectors can be fitted to the PCB. The board has provision for a dual USB type-A vertical connector to be used. Alternatively, a single vertical type-A connector can be fitted in the same location, or a horizontal type-A connector (they have the same pin spacing). Which one you use depends on the particular way you are going to install the board.

It's also possible to fit off-board connectors via flying leads, which is what we had to do in the Honda Accord we fitted the prototype to, due to limited space in the reading lamp assembly. For other applications, you can simply run a figure-8 lead from the two pads provided on the board. This can be strapped to the blank area at the bottom of the PCB with a cable tie for strain relief.

Normally, for a USB charger, the D+ and D– lines (green and white wires in the cable) are shorted together. This tells the connected device that it's plugged into a charger rather than a computer, so it can immediately draw more than 100mA. With a computer, a device has to negotiate to draw more than this – but in our circuit there's nothing to 'talk' to the USB device.

For the circuit's power input, you can either fit a small terminal block, a pin header or just wire it up via flying leads. The flying leads will take up the least space, although we used a right-angle pin header to make installation easier.

Construction

The PCB overlay diagram is shown in Fig.7. Note that while we're showing the PCB as a single-sided design (as indeed it is), the boards we supply are double-sided with a full ground plane on the underside. This should help reduce EMI and also slightly improve efficiency.

As stated earlier, most of the components are SMDs. Only the connectors are through-hole parts. REG1 is in an 8-pin SOIC package which has a convenient 1.27mm pin spacing, so it's not hard to solder.

Start the assembly of the PCB by fitting REG1. While an SOIC-8 package is generally easy to solder, this one has a thermal pad on the underside which is also supposed to be soldered to the board. To do this properly, you need to use a hot-air rework station. These are available from eBay sellers for around £30 (eg, search for 'Atten 858d').

If you have one of these, simply apply some solder paste to each pad, place the IC on top, check its orientation carefully (pin 1 to upper left) and then heat the IC and its leads until the solder reflows. Be sure to continue heating it long enough for the solder on the thermal pad to melt also; you can usually see fumes from the flux escaping under the IC.

While we recommend this method, it is possible to solder the chip by hand. To do this, first place a small amount of non-conductive (silicone-based) heatsink paste on the central pad and clean the residue off the other pads. That done, tin one of the eight remaining pads, carefully place the IC in position and reheat that pad while pressing down gently on the IC until its lead contacts the PCB.

Once it's in place, check the alignment, then solder the remaining seven pins and add some solder to that first pin to refresh the joint. Any solder bridges between pins can then be easily cleaned up using solder wick.

Note that it's best to avoid moving the IC by much during soldering, so that the heatsink paste is not spread around. Also, don't clean the board using any solvents as these are likely to wash the paste away.

One of the most common problems with soldering an IC like this is that it's possible to get solder on a pin without it actually flowing onto the corresponding pad. **As a result, it's best to check all eight leads under a magnifying lamp to make sure the solder fillets are properly formed.**

With REG1 in place, L1 is next. This is a little tricky due to its high thermal inertia. There are various methods but the simplest is to treat it like a large chip component. This involves adding a fair bit of solder to one of the pads, enough that it's visibly built up, then heating this solder while sliding L1 into place along the surface of the PCB. It's easiest to do this while holding it with angled tweezers.

As soon as L1 hits the solder, some of it will cool and solidify. You will have to hold the iron in place while L1 heats up and the solder will then re-melt. Once that happens, you can finish sliding L1 across into the correct position between the two pads.

You can then flow solder onto the opposite pad.

Note that it's best to do this immediately before L1 cools down. Note also that it will take a little while to apply enough heat to form a good joint. Make sure a proper glossy solder fillet is formed.

You will then need to go back and add some more solder and heat to the initial pad, until you get a similarly good fillet on that side; much of the flux will have boiled off during the initial soldering process.

The rest of the components are much easier as they are substantially smaller but you can use the same basic idea of adding solder to one pad and then sliding the part into place. The only remaining polarised components are D1 and ZD1; in each case, the cathode (striped) side goes towards the nearest edge of the PCB.

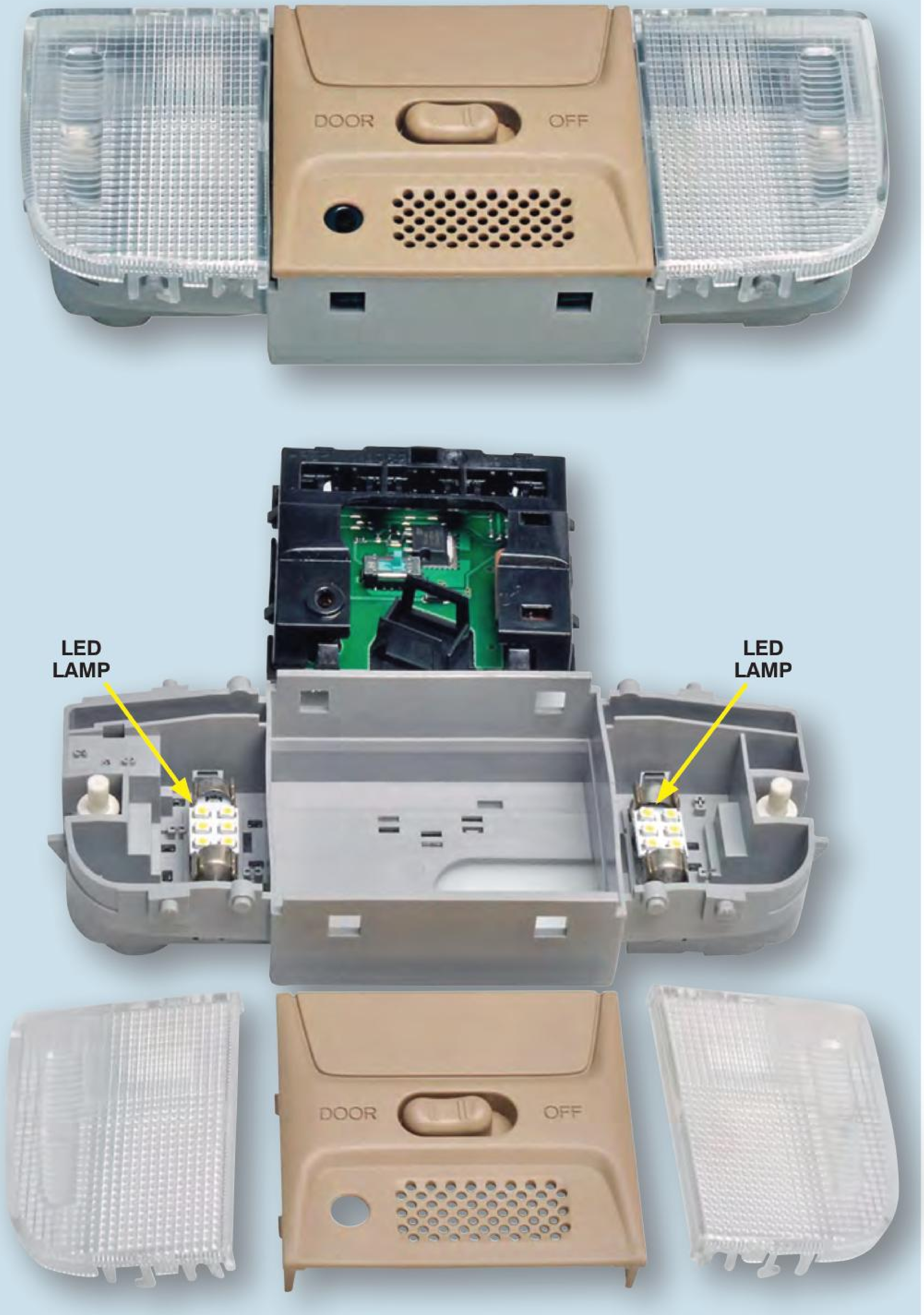
Don't get any of the different value capacitors, resistors or diodes mixed up. The resistors will have printed value codes on the top but the other components are likely to be unmarked so you will have to remove them from their packaging one at a time and immediately solder them into the correct locations.

Fitting CON1 and/or CON2

Finally, fit your choice of CON1 and CON2 in the usual manner. It isn't strictly necessary but if you are using a horizontal socket for CON2, you may want to place some insulation over the unused set of pads near the edge of the board, to prevent the shell shorting to them. We say this is probably not necessary because those pads should be covered with solder mask on the top side of the board and so there's unlikely to be enough exposed metal for the connector shell to touch.

Note that soldering the retaining posts for CON2 may be a little tricky as there isn't much 'meat' on the pads, since they are pretty close to the edge. However, if you apply enough heat and flow a sufficient amount of solder into the mounting holes, it should adhere to the copper plating inside the holes and provide a good mechanical connection.

When the PCB is finished, carefully check your work and then connect it to a source of 12V or it could even be initially powered from a 9V battery. Make sure you connect it with the correct polarity, otherwise nothing will work.



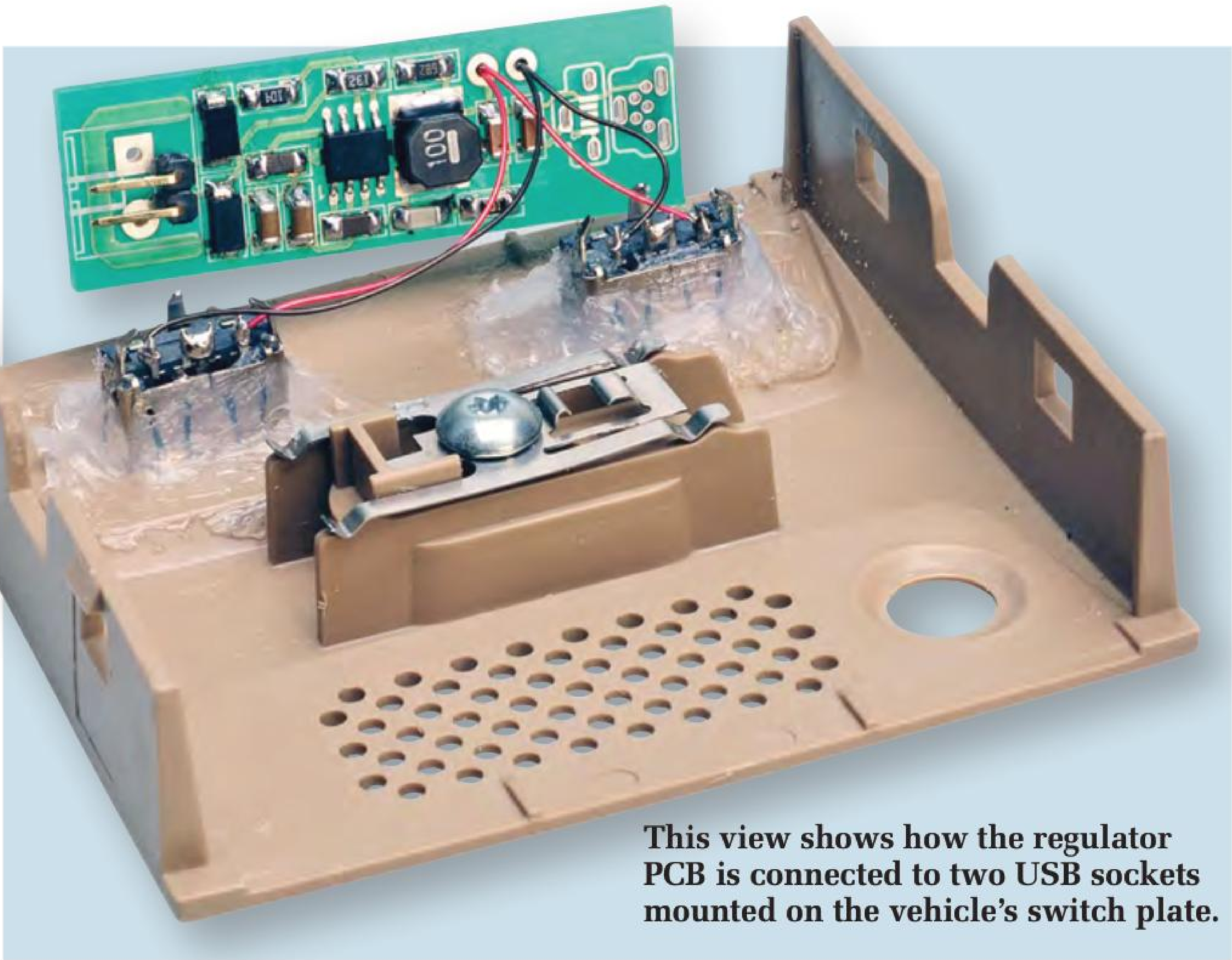
These two photos show the reading/courtesy light assembly after it had been removed from the car (top) and after it had been stripped down to its major sub-assemblies. The standard incandescent lamps should be changed to 12V LED lamps to reduce the overall power consumption (see text).

Once powered, check that you have 5V (or very close to 5V) at the relevant points on the USB socket (on the back of the PCB). If that checks out OK, you are ready to install it.

Fitting it in your car

Depending on your application, it's up to you how you wire up and secure the assembly. A short length of clear heatshrink tubing is a good way to encapsulate the board if it isn't going to be held rigidly in place. But now we're going to show you how we fitted in into a test car. The details for other cars will be different but the general principles should apply across many common models.

First, most vehicles will have 12V power permanently available in the reading lamp assembly. If you wire the unit up to that power, the USB



This view shows how the regulator PCB is connected to two USB sockets mounted on the vehicle's switch plate.

sockets will be constantly on. Of course, you could add a switch to turn it off when not needed (which may be easier than turning the connected devices on and off each time) but we didn't bother.

While the circuit only draws about 1mA by itself, you will need to switch any GPS navigation units or dash cameras on/off manually as they won't be switched automatically with the ignition, as they are when powered from an accessory socket.

And if you are going to install the PCB inside the reading/courtesy lamp assembly, we strongly suggest that you change the standard incandescent lamps to 12V LED fittings. This is desirable to reduce overall heat production inside the housing and also to reduce the overall current drain from the car's 12V courtesy light bus.

Anyway, the first step to fitting the unit is to remove the light assembly. In our car, we first pushed in each reading lamp lens in turn, then slid a slim flat-bladed screwdriver wrapped in a cotton cloth under the edge and prised the clear plastic cover off (as described in the vehicle manual). This revealed the head of a retaining screw on each side.

Removing the two screws required a large screwdriver and quite a bit of force – they were done up very tightly and we didn't want to strip the heads. The whole lamp assembly then came down from the roof. We simply had to unplug two multi-way cables and the whole thing could be removed.

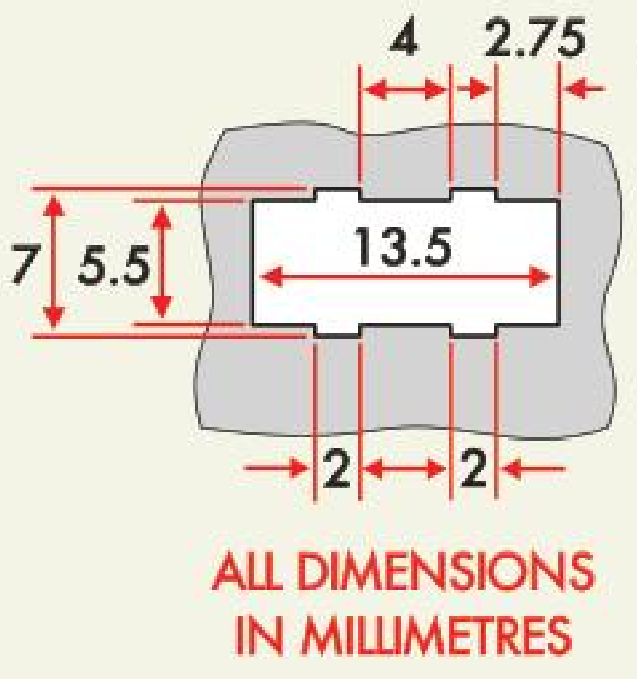
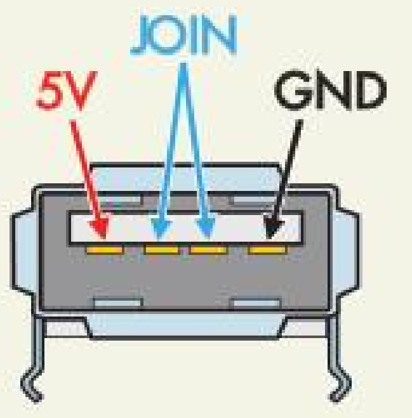


Fig.8: use this diagram as a template for marking out the USB socket cut-outs. Note the notches on either side.

Fig.9: the OUT+ (5V) and OUT– (GND) pads on the PCB are connected to the USB sockets as shown here.



To remove the brown plastic cover from the centre section, we used the same screwdriver to press in the four plastic tabs at top and bottom. The whole central assembly was then removed and four further clips had to be pressed in to separate this into two further sections, as shown in one of the photos.

The lower black plastic section contains a PCB with a MOSFET to control the light dimming, the switch to control whether the courtesy lamp comes on when the doors are opened, an LED to illuminate the gear shift lever and a few other bits and pieces.

Finding 12V power

Since this module included the MOSFET to control dimming, it seemed likely that there was a permanent source of 12V power connected to the board. We examined the PCB for likely points where this might be connected (eg, the source tab of the MOSFET), then plugged the board back into the car's electrical system and checked each point for continuity with the vehicle's chassis via the exposed metal where the retaining screws had been.

We got a reading of less than one ohm from one of these tracks to the chassis and made a note of its location as this was a good place to connect the USB power supply ground. We then switched the DMM into voltmeter mode, connected the black probe to chassis and probed other large tracks with the red probe. We quickly found a track which reliably gave us a reading of around 12.5V; we noted this also.

It was then just a matter of scraping back a little of the solder mask on these two tracks and soldering some red and black wires with a 2-way DuPont-style header plug on the other end (see photo on facing page).

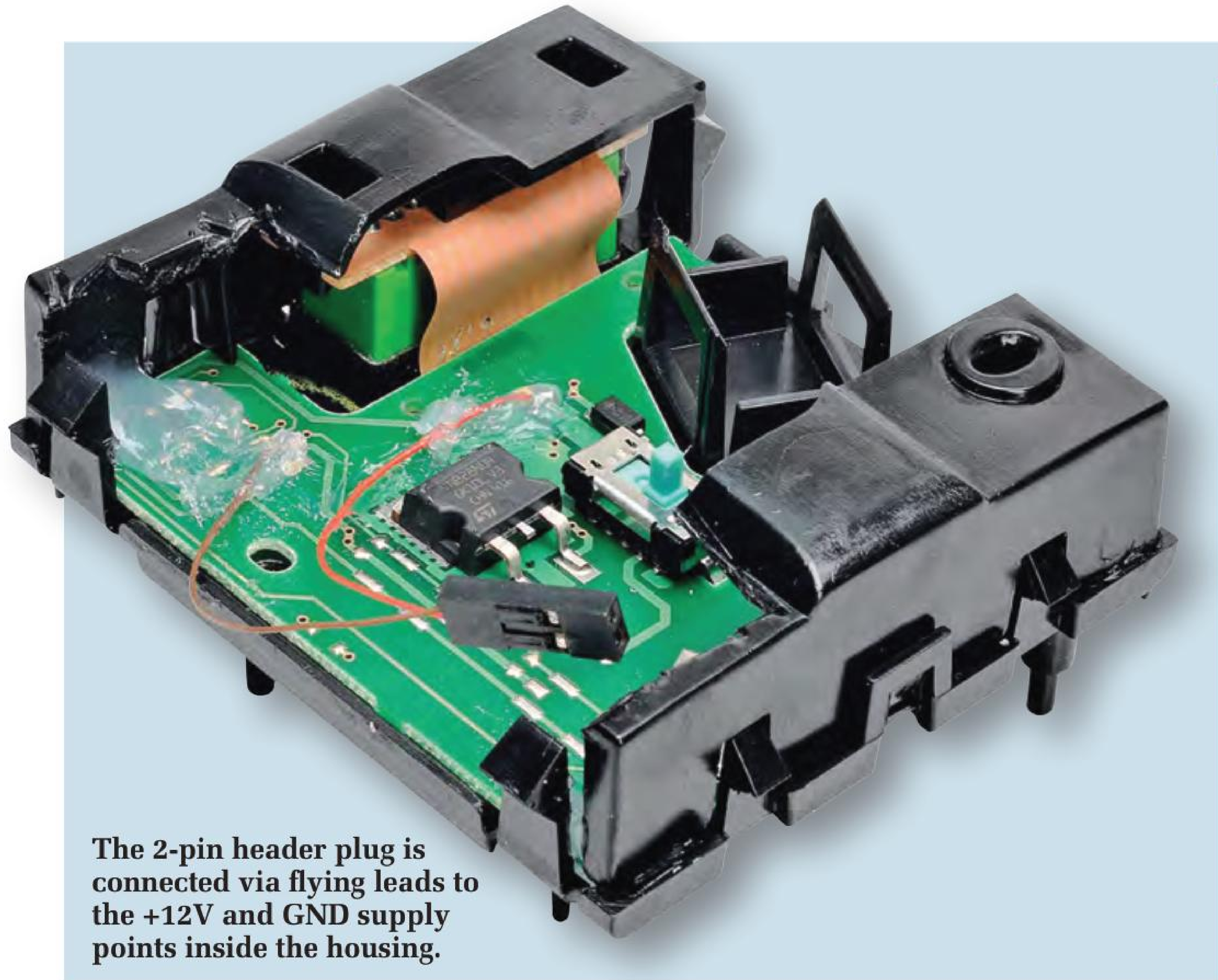
Installing USB sockets

The next task was to fit sockets on the blank plastic plate between the two reading lamps. Ideally, we would have used a panel-mount USB socket but there simply wasn't room. These also tend to be fairly expensive compared to normal PCB-mounting USB sockets.

Instead, we decided to press a couple of regular vertical PCB-mounting sockets into service. The idea was to drill a series of holes in the panel, then use files to shape the holes into rectangular slots and secure the sockets in place with silicone sealant.

This approach is workable but there are a few catches you need to be aware of. First, typical USB sockets are designed to mount behind a thin steel or aluminium plate and there are six spring-loaded clips arranged just behind the front of the socket which hold the USB plug in place using friction, so it doesn't fall out. A thicker plastic panel can interfere with these springs and cause the insertion and retention force to be much higher than desirable.

Similarly, you have to be careful when gluing the socket in to avoid glue getting inside the socket (as they typically aren't sealed) and also to avoid gluing the springs in place! If you do this it will be virtually



The 2-pin header plug is connected via flying leads to the +12V and GND supply points inside the housing.

Parts List

- 1 PCB available from the *EPE PCB Service*, coded 18107151, 16 × 51mm
- 1 4.7-10µH 2.5A RMS (3A saturation) 6 × 6mm SMD inductor, eg, NR6045T100M (L1)
- 1 2-way mini terminal block or pin header (CON1) (optional)
- 1 dual stacked vertical type-A USB socket, through-hole mounting (CON2) OR
- 2 vertical or horizontal type-A USB sockets, through-hole mounting (CON2)
- 1 50mm length of 20mm-dia. heatshrink tubing

Semiconductors

- 1 RT8299AZSP 3A Switch-mode Step-down regulator IC (REG1)
- 1 3A 30V Schottky diode, DO-214AC (D1)
- 1 SMAJ15A SMD 15V 400W TVS or equivalent (TVS1)

Capacitors

- 2 22µF 16V X5R/X7R SMD 3216/1206*
- 2 10µF 25V X5R/X7R SMD 3216/1206*
- 2 100nF 50V X7R SMD 3216/1206*
- 1 100pF 50V C0G/NP0 SMD 3216/1206*

Resistors (SMD 3216/1206*, 1%, 0.25W)

- 1 100kΩ
- 1 6.8kΩ
- 1 1.3kΩ
- 1 100Ω

* 2012/0805-size parts are also suitable

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impossible to insert a USB plug and if you do somehow manage to do it, good luck getting it out!

Ultimately, we came up with the following approach. First, we profiled the holes to leave a little extra clearance in the places where the springs sat to allow them to move. We then secured the socket in place using silicone sealant which, while very strong, is flexible enough to allow the springs to move in order to keep the insertion and retention forces to a more-or-less normal level.

Cutting the holes

First, decide where the sockets are to be fitted and keep in mind that there needs to be enough room behind the panel for them to project into, without the risk of shorting to anything conductive. Also, you need to leave enough room for the DC/DC converter PCB to fit.

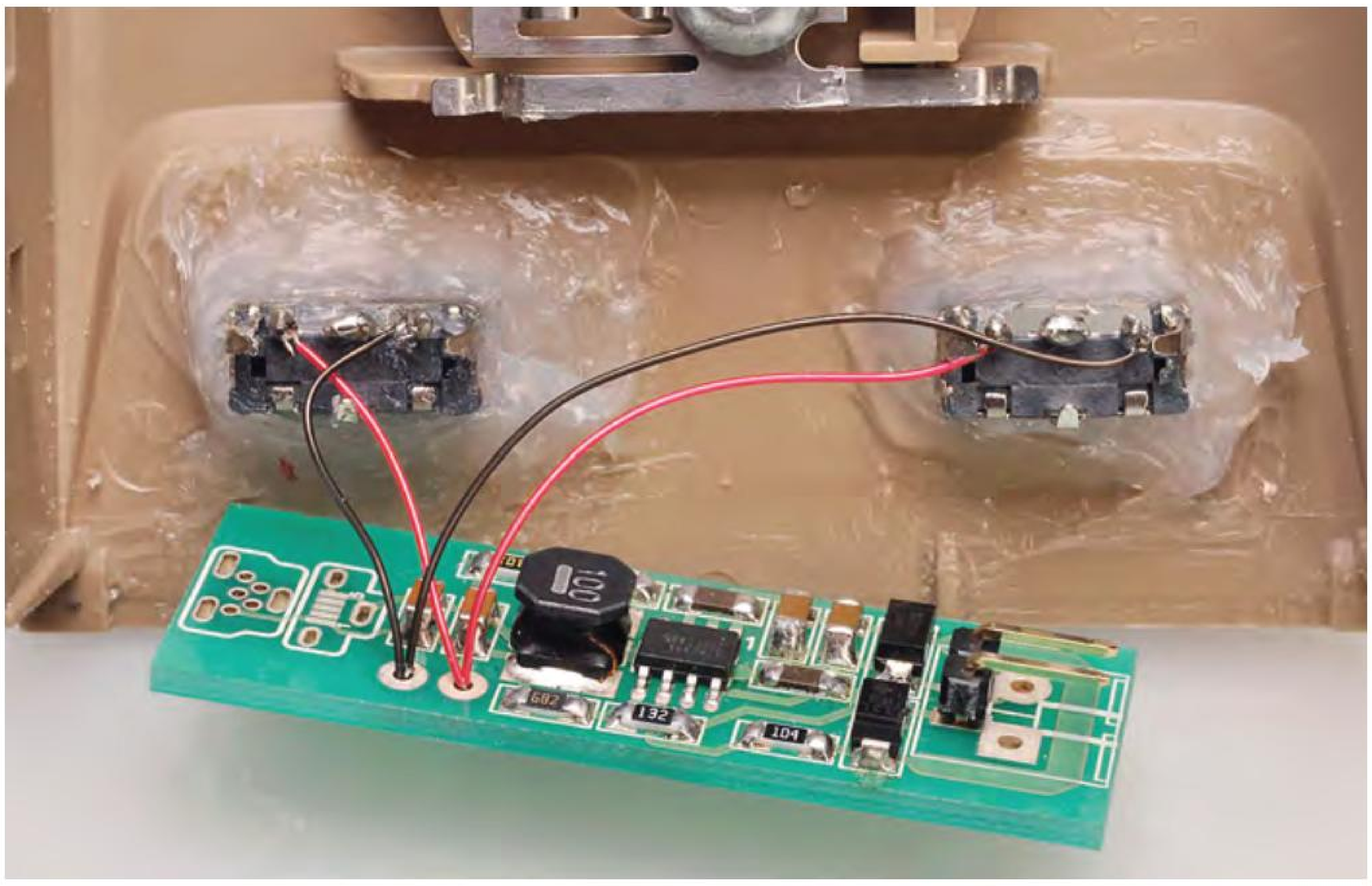
In our case, the logical place to mount the sockets was evidently intended to house three extra illuminated buttons or lamps which were not fitted to this vehicle. As a result, we had to cut away the plastic that would have held these devices in place to make room for the sockets. As luck would have it, this also left enough room to fit the regulator board just behind the sockets. You can see the modifications made to the black plastic frame in the accompanying photograph.

We then marked out the socket locations on the brown plastic fascia and drilled three 5mm holes spaced slightly apart in each location. We then slowly filed these into a rectangular shape until the sockets fitted through and were held in place by friction – but only just. If the sockets fit too tightly, this will make it difficult to plug the cable in.

We then used a small round file to make four small notches in each cutout, corresponding to the two pairs of spring clips on the top and bottom surfaces of the sockets. This gives the clips some room to expand when a plug is inserted. The notches are 6mm apart and only about half a millimetre deep – see Fig.8. Any deeper than this and they won't be covered by the flange surround on the front face of the socket.

We then pushed each socket into its corresponding hole and checked that it was possible to insert and remove a USB plug with a reasonable amount of force. You will need to get a good hold onto the rear of the socket to test unplugging. We then applied silicone sealant around all the edges of the socket where it met the plastic panel and left it for 24 hours to set.

Try to avoid pushing too much sealant into the spring clip holes and definitely avoid getting any on the solder tabs, especially since there is usually a large hole in the back of the socket. If you do get some silicone inside the front of the connector (ie, near the entry side), you can remove it carefully using the tip of a sharp hobby knife.



The two USB sockets can be secured to the switch plate cover using neutral-cure silicone adhesive and wired as shown here. Note that two centre pins on each socket are shorted together with solder.

Pre-made units

If you don't want to build your own, you can buy pre-made USB sockets that can be simply wired into a 12V automotive supply (eg, Jaycar PS2016, Altronics P0664/P0668/P0676).

However, these are quite bulky and are designed to be fitted to or under the dash. As a result, they're a lot less convenient to use for something like a dashcam and you will also have to rummage around behind the dash to connect them to the vehicle supply.

Wiring it up

Now for the final connections. As stated earlier, we connected a 2-pin header plug to the 12V and GND supply points inside our housing and if you haven't already done something similar, do it now. This then plugs into the 2-pin header on the PCB.

You will then need to solder wires to the rear of the USB sockets – use Fig.9 as a guide. The two central pins can simply be joined with a solder bridge or if you can't get one to form, use a small piece of tinned wire (eg, a component lead off-cut).

The 5V and GND pins of the two sockets are wired up to the outputs on the regulator PCB in parallel. We did this by running a separate pair of wires from each socket to the solder pads on the board, but you could run wires between the two sockets if you prefer.

Be very careful to follow the pinout diagram of Fig.9 and observe the polarity of the output pads on Fig.7. Most USB devices won't have reverse polarity protection and will probably be damaged if the sockets are wired up incorrectly!

Once you've done that, you can slip a piece of heatshrink tubing over the DC/DC converter board and plug the 2-pin header in (be careful with polarity – see Fig.7) before shrinking the tubing down.

It's then simply a matter of reassembling the whole thing while tucking the regulator board away inside it. Plug the connectors back into the vehicle's wiring harness and secure the lamp assembly in place in the vehicle. You can then plug a USB device with some sort of power indicator in to test it. We suggest something cheap! We used a card reader to verify that the USB power supply was working correctly on both sockets before plugging in our GPS unit and dashcam.

Quiescent current/power draw

The DC/DC converter board only draws around 1mA so, by itself, it will add only a negligible load to the battery, even when wired in permanently. However, be aware that anything you leave plugged into the sockets could draw significantly more than this and may flatten the vehicle battery if it isn't driven for long periods. This could be true even if the device(s) plugged in are switched 'off' – they may still be drawing current to keep their batteries topped up.

The only way to know for sure is to measure it. Once you know the current, divide it in two to get an idea of how much extra load it places on the vehicle's battery.

Let's say, for example, that you have a GPS and a dashcam plugged in and you've measured their total current drain when switched off at 10mA. This means the load on the vehicle battery will be roughly 10mA ÷ 2 + 1mA (regulator quiescent current) = 6mA. Over 24 hours, that represents a drain of 0.006A × 24h = 0.144Ah.

As a result, it will take several weeks to discharge a fully charged vehicle battery and thus such a load would be fine to leave connected, as long as the vehicle is driven regularly.

A typical vehicle will draw maybe 30mA from the battery with the ignition switched off. So adding another 30mA will halve the time until the vehicle will no longer be able to turn the engine over. We would be reluctant to leave any load drawing more than this connected long-term.

Fusing

The regulator board will draw a little over 1A at maximum output. The vehicle's reading lamp supply will be fused and a typical fuse would be 5A. Chances are this will have enough excess capacity to handle the added draw, but to be sure you will have to add up the wattages of the lamps on this circuit. You could change the fuse to a slightly higher-rated type if necessary.

Win a Microchip 3DTouchPad

EVERYDAY PRACTICAL ELECTRONICS is offering its readers the chance to win a Microchip 3DTouchPad. Microchip introduces the first 2D/3D input sensing development platform. The 3DTouchPad (DM160225), is a production-ready development kit and reference design which combines 2D tracking of up to ten fingers, with 3D air gesture recognition for fast development of advanced input sensing for PC peripherals and other applications.

Based on Microchip's GestIC technology, 3DTouchPad's robust and innovative 3D gesture recognition technology offers a detection range of up to 10cm, while the highly responsive 2D projected-capacitive multi-touch input sensing supports up to 10 touch points and multi-finger surface gestures.

As a plug-and-play PC peripheral, 3DTouchPad connects to a PC using a single USB cable and includes a free Graphical user interface (GUI), software development kit (SDK) and application programming Interface (API). It also offers out-of-the-box driverless features to enhance the user experience for Windows 7/8.X and MacOS.

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CLOSING DATE

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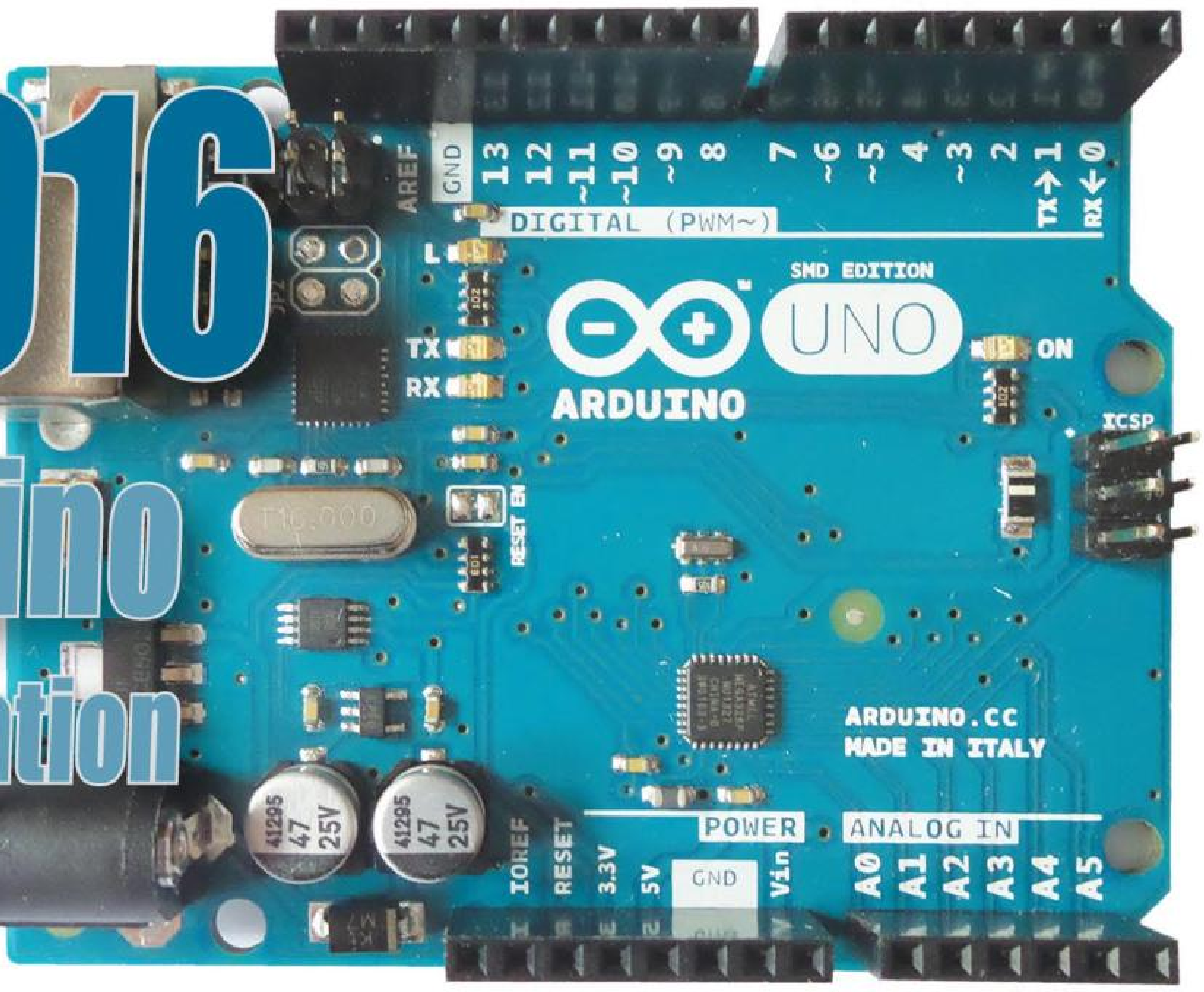
Teach-In 2016

Exploring the Arduino

Part 6: Wireless communication

by Mike and Richard Tooley


AREF
GND 13 12 ~11 ~10 ~9 8 7 ~6 ~5 4 ~3 2 TX→1 RX←0
DIGITAL (PWM~)
L
TX
RX
SMD EDITION
UNO
ARDUINO
ON
ICSP
ARDUINO.CC
MADE IN ITALY
POWER
ANALOG IN
IOREF RESET 3.3V 5V GND Vin A0 A1 A2 A3 A4 A5

Welcome to *Teach-In 2016 – Exploring the Arduino*. This exciting new series has been designed for electronics enthusiasts wanting to get to grips with the immensely popular Arduino microcontroller as well as coding enthusiasts who want to explore hardware and interfacing. So, whether you are considering what to do with your Arduino, or maybe have an idea for a project but don't know how to turn it into reality, our new *Teach-In 2016* series will provide you with a one-stop source of ideas and practical information.

In last month's *Teach-In 2016 Exploring Arduino* we looked at ways in which the Arduino can handle multiple sensors using a limited number of wire connections. To help with this task, *Arduino Workshop* introduced the highly versatile 1-wire bus system, while *Arduino World* looked at temperature sensors that have their own integrated ADC offering a much higher resolution than the ADC converters built into the Arduino Uno. Our programming feature, *Coding Quickstart*, showed you how to use some code to store your valuable data on an ordinary SD card. Finally, our *Get Real* project took the form of a stand-alone environmental monitoring system that can capture large amounts of data, conveniently processing and storing it on a conventional SD memory card.

This month

In this month's *Teach-In 2016: Exploring the Arduino* we will be looking at ways in which an Arduino can communicate with remote devices using low-cost wireless modules. To this end, *Arduino World* will introduce wireless transceivers, while *Arduino Workshop* looks at configuring a short-range wireless data-link that will allow you to send data from one Arduino to another. Our programming feature, *Coding Quickstart*, introduces the RadioHead Packet Radio library for embedded microprocessors. Finally, our *Get Real* project will take the form of a simple wireless-linked rain alarm.

Arduino World: Using wireless modules

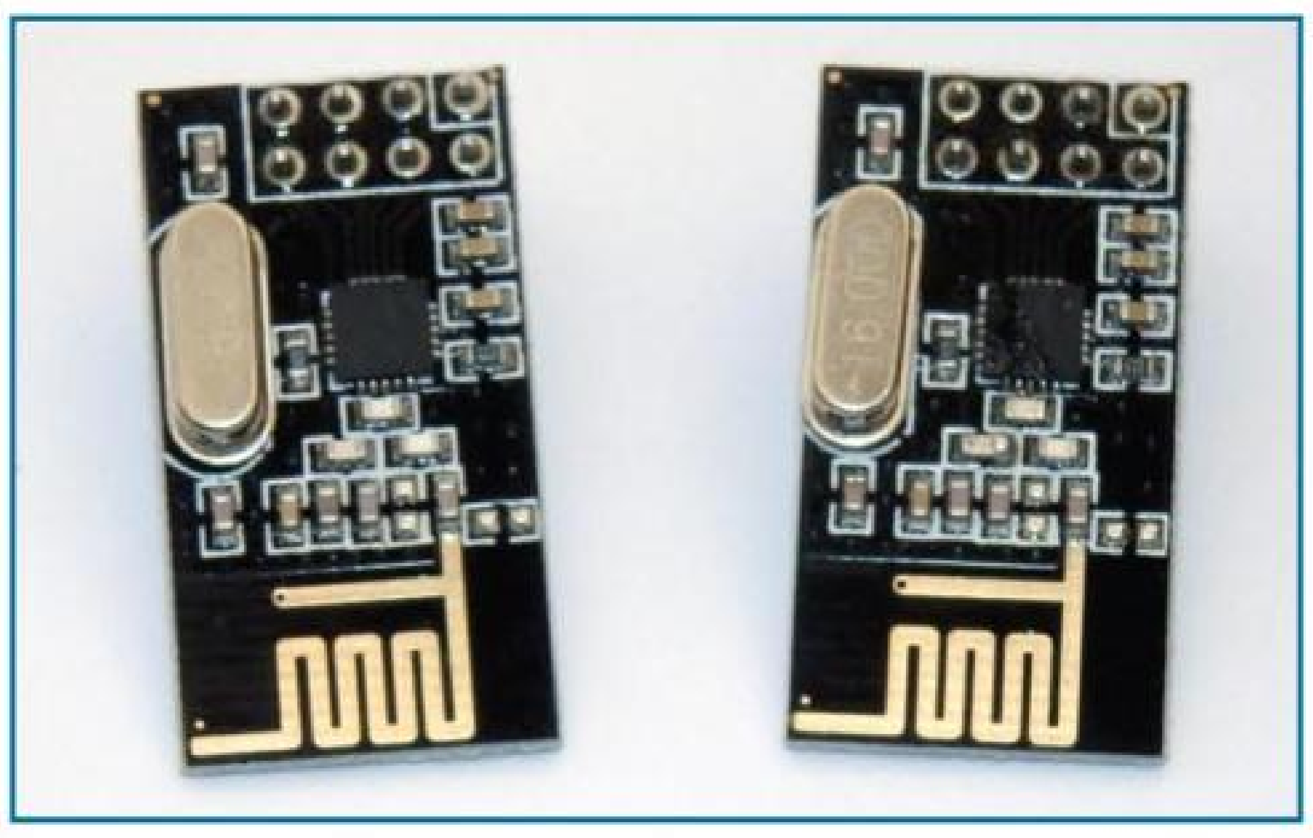


Fig.6.1. Two nRF24L01 wireless transceivers – note the quartz crystal frequency reference and printed 2.4GHz antenna

An increasing number of microcontroller applications can benefit from the use of wireless to transfer data from remotely placed sensors or to transfer data from one Arduino to another. Fortunately, there's a range of cost-effective solutions that will allow you to dispense with wired or cabled connections, allowing you to transfer data quickly and easily between participating devices. To send and receive data you will need a radio frequency (RF) transmitter/receiver or 'transceiver' at each end of the link, and one of the easiest to use is the nRF24L01+.

The nRF24L01+

The nRF24L01+ from Nordic Semiconductor is a single-chip 2.4GHz transceiver that incorporates an embedded protocol engine that handles the transfer of data to/from the microcontroller. The device is ideal for use in a wide range of low-cost low-power wireless applications, and it is designed for operation in the globally available Industrial Scientific and Medical (ISM) band (see later).

The simplified internal schematic of the nRF34L01 is shown in Fig. 6.2. We've divided the schematic into six functional blocks:

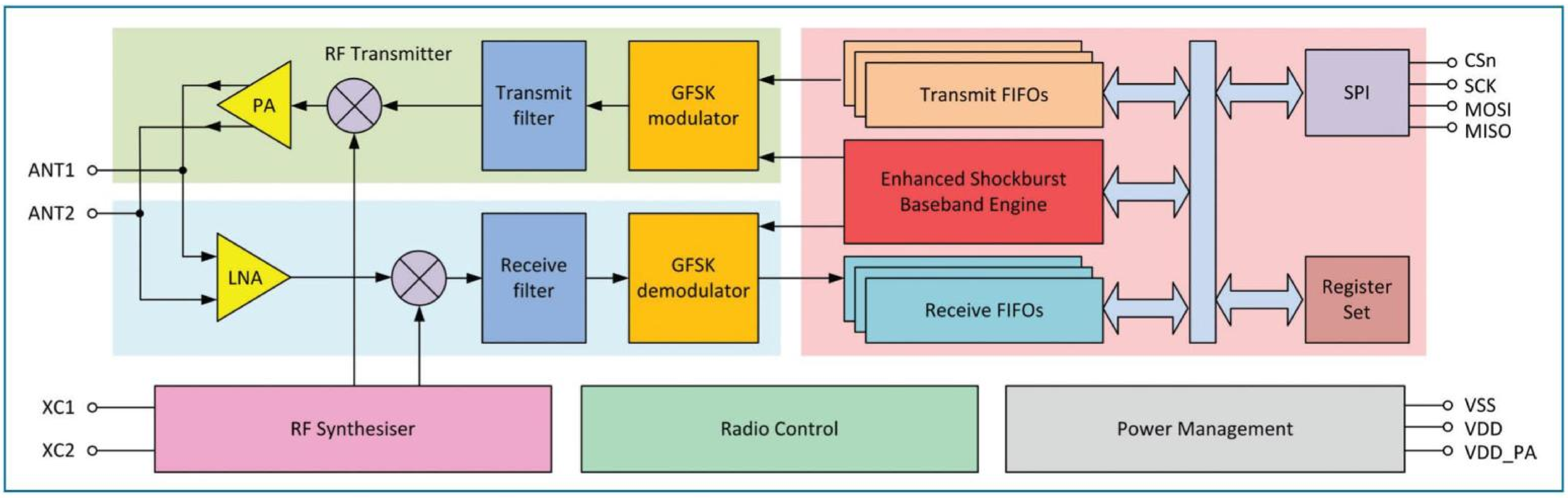

RF Transmitter
PA
Transmit filter
GFSK modulator
Transmit FIFOs
SPI
CSn
SCK
MOSI
MISO
ANT1
ANT2
Enhanced Shockburst Baseband Engine
LNA
Receive filter
GFSK demodulator
Receive FIFOs
Register Set
XC1
XC2
RF Synthesiser
Radio Control
Power Management
VSS
VDD
VDD_PA

Fig.6.2. The simplified internal schematic of an RF24L01 wireless transceiver chip

- RF transmitter (a low-power 2.4GHz transmitter)
- RF receiver (a sensitive 2.4GHz receiver)
- RF synthesiser (to generate the required 2.4GHz channels from a stable quartz-crystal-controlled reference oscillator)
- Internal first-in first-out (FIFO) registers for storing transmitted and received data (which is sent serially) together with a protocol engine, general purpose registers and a serial peripheral interface (SPI) linked together via an internal data bus
- Control logic for the RF section (ie, radio control)
- Power management logic (making it possible to operate the chip in one of several power saving modes).

The chip's SPI interface makes it extremely easy to interface the device to a microcontroller. The interface provides access to the chip's internal registers so that the device can be configured for operation in various ways. The RF front end uses Gaussian frequency shift keying (GFSK). This is more efficient than conventional frequency shift keying (FSK) and is the same method of digital modulation used with Bluetooth devices. The chip's operating parameters, such as channel/frequency, output power and transmitted data rate, are user-programmable and its embedded baseband protocol engine is based on standard packet communication techniques.

The nRF24 family

There are several members of the NRF24 family. The latest device (nRF24L01+) is pin compatible with the nRF24L01 and on-air compatible with nRF2401A, nRF2402, nRF24E1 and nRF24E2. It is worth noting that the nRF24L01+ offers significantly better performance than its predecessor (notably intermodulation and wideband blocking). The addition of internal filtering in the latest version of the chip has helped improve the margins for meeting national and international RF regulatory standards.

The 2.4GHz Band

The ISM band extends from 2.400 to 2.4835GHz and it has become immensely popular for use in a wide variety of short-range license-free applications. The band is used worldwide for services such as Bluetooth and limited-range wireless networks that provide Internet access. The various Wi-Fi channels are listed in Table 6.1. It is important to be aware that while most of the world has access to channels 1 to 11 (2.42 GHz to 2.462 GHz), there are restrictions to the use of bands 12, 13 and 14.

Unfortunately, the increased popularity of Wi-Fi and Bluetooth has led to congestion and interference can often be a problem, particularly in densely populated areas. Note also that domestic microwave ovens also operate in this band and they work at appreciable power levels. Leakage from a poorly designed microwave oven, although intermittent in operation, can spread over a wide area.

Table 6.1 Wi-Fi channels

Wi-Fi channel number	Frequency (GHz)
1	2.412
2	2.417
3	2.422
4	2.427
5	2.432
6	2.437
7	2.442
8	2.447
9	2.452
10	2.457
11	2.462
12	2.467 (note 1)
13	2.472 (note 1)
14	2.484 (note 2)

Notes

1. In the US channels 12 and 13 are restricted
2. Channel 14 is only currently available in Japan

nRF24L01 channels

The nRF24L01 can be programmed for operation in any of 125 channels inside the 2.4GHz ISM band. These channels extend from 2.400GHz to 2.525GHz with a channel spacing of 1MHz. In order to determine the channel, a corresponding value needs to be written to the chip's channel register. The selected channel needs to comply with the regulations in your country. For example, in the US the Federal Communications Commission (FCC) permits operation in the band 2.400 GHz to 2.4835MHz, which is equivalent to the first 84 channels (numbers 0 to 83) used with the nRF24L01. For best performance, it is important to avoid heavily used Wi-Fi channels in your locality. We will show how this can be done later in this month's *Get Real*.

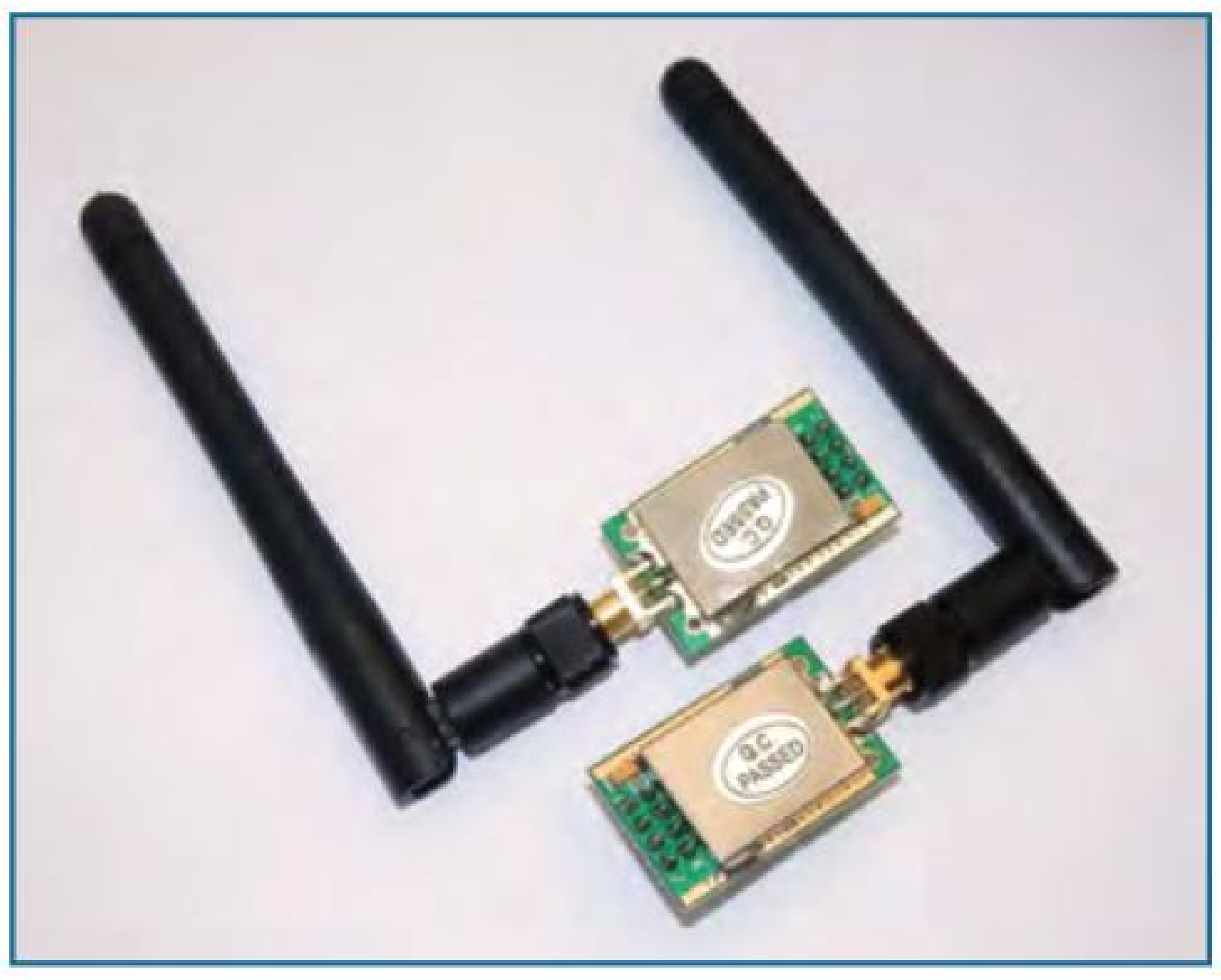


Fig.6.3. High-power versions of the nRF24L01 wireless module fitted with external antennas

Range

The range that can be achieved using typical low-power 2.4GHz wireless modules is usually between 10m (inside a building) and up to about 100m on a line-of-sight path. With higher power output and an external antenna (see Fig. 6.3), the range can be increased to about 30m inside a building and over 500m using a line of sight path between the transmitter and receiver.

Output power

The transmitter output power is programmable in one of four levels; 0, -6, -12 or -18dBm (note that 'dBm' means decibels relative to 1mW; for example, -6dBm corresponds to an output power of about 250µW). When the output power is configured to its maximum (0dBm) the chip needs a supply current of about 11 mA.

Data rate

The transmitter data rate (or air data rate) is the modulated signalling rate the nRF24L01+ uses when the RF front end is transmitting or receiving data. The data rate can be 250kbps, 1Mbps or 2Mbps. Note that, while using a lower air data rate gives better receiver sensitivity, the average current consumption is greater than with a high data rate and there is also increased probability of on-air collisions.

Setting the channel, data rate and output power

The channel, data rate and power can be easily set by writing values to the chip's internal registers. It should go without saying that a transmitter and a receiver must be programmed with the same data rate and channel in order to be able to communicate with each other! In *Arduino Workshop* we will show how this is done.

Arduino Workshop: Configuring a wireless data-link

When implementing a data-link between two Arduinos (see Fig. 6.4) one microcontroller needs to be configured as a 'server', whilst the other must be configured as a 'client'. To do this you will need two different programs – eg, `nrf24_server.pde` and `nrf24_client.pde` respectively. These two programs are available in the Examples folder of the RadioHead library. The code needs to be installed and uploaded using the Arduino IDE and the serial port monitor on the client Uno used to monitor the received data.

The library examples include some useful setup code that will allow you to check that the RF modules have been detected and initialised correctly. The code also confirms that various RF parameters have been set correctly. These include channel selection, data rate and transmit power, as shown in Listing 6.1.

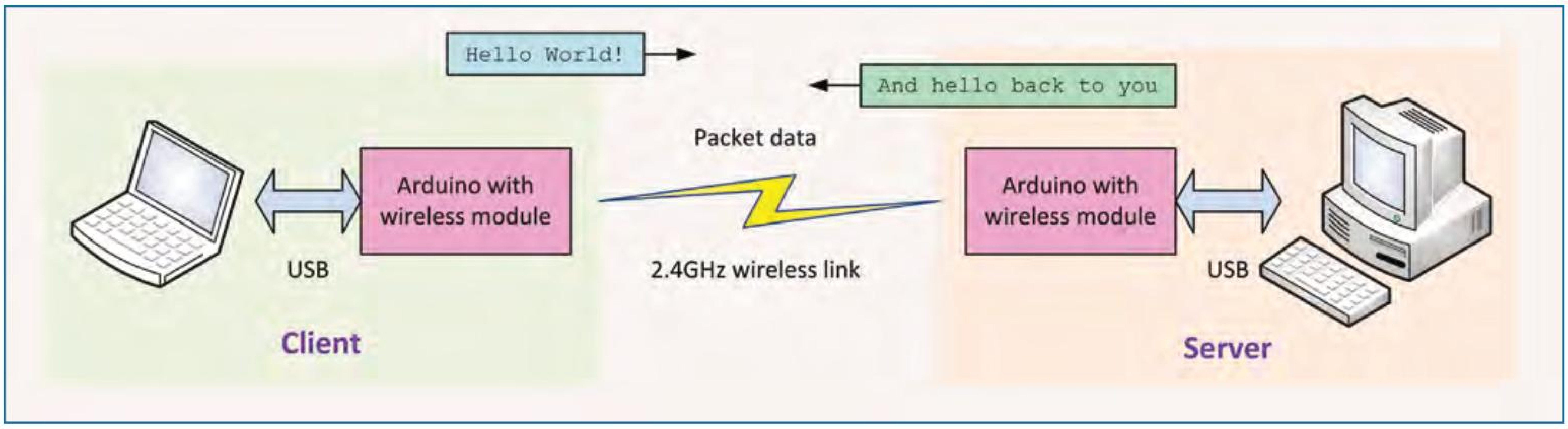


Fig.6.4. Simple Arduino wireless data-link

Note how an appropriate error message is sent to the serial monitor if any part of the setup code fails.

If both Arduinos have been initialised correctly the data-link will be established and data will be transferred from the server to the client. The client's serial monitor will display a message like that shown in Fig. 6.5. If, however, the client cannot receive data from the server (eg, if the server is out of range) a message like that shown in Fig. 6.6 will be displayed.

Coding Quickstart : Using the RadioHead library

In order to use an RF transceiver module based on a chip like the nRF24L01, you will need to use a library that supplies the low-level code that allows you to access the chip and configure it in various ways. However, before delving into the RF library you will need to use the standard Serial Peripheral Interface bus (SPI) library to handle the transfer of data between the Arduino and the RF module. This can be accomplished by including the SPI library (`SPI.h`) in your code.

The SPI bus

As mentioned last month, the SPI bus is a serial clocked bus capable of supporting data transfer in both directions, master to slave and slave to master. The Arduino's SPI implementation uses four signal wires (plus ground). These are listed in Table 6.2, together with the pin connections conventionally used on the Uno.

Listing 6.1 Configuring the nRF24L01 data-link

```
#include <SPI.h>
#include <RH_NRF24.h>

RH_NRF24 nrf24;  // use the default Uno SPI pins

void setup()
{t
  Serial.begin(9600);
  while (!Serial)
    ; // wait for serial port to connect. Needed for Leonardo only
  if (!nrf24.init())
    Serial.println("init failed");
  // Defaults after init are 2.402 GHz (channel 2), 2Mbps, 0dBm
  if (!nrf24.setChannel(1))
    Serial.println("setChannel failed");
  if (!nrf24.setRF(RH_NRF24::DataRate2Mbps, RH_
NRF24::TransmitPower0dBm))
    Serial.println("setRF failed");
}
```

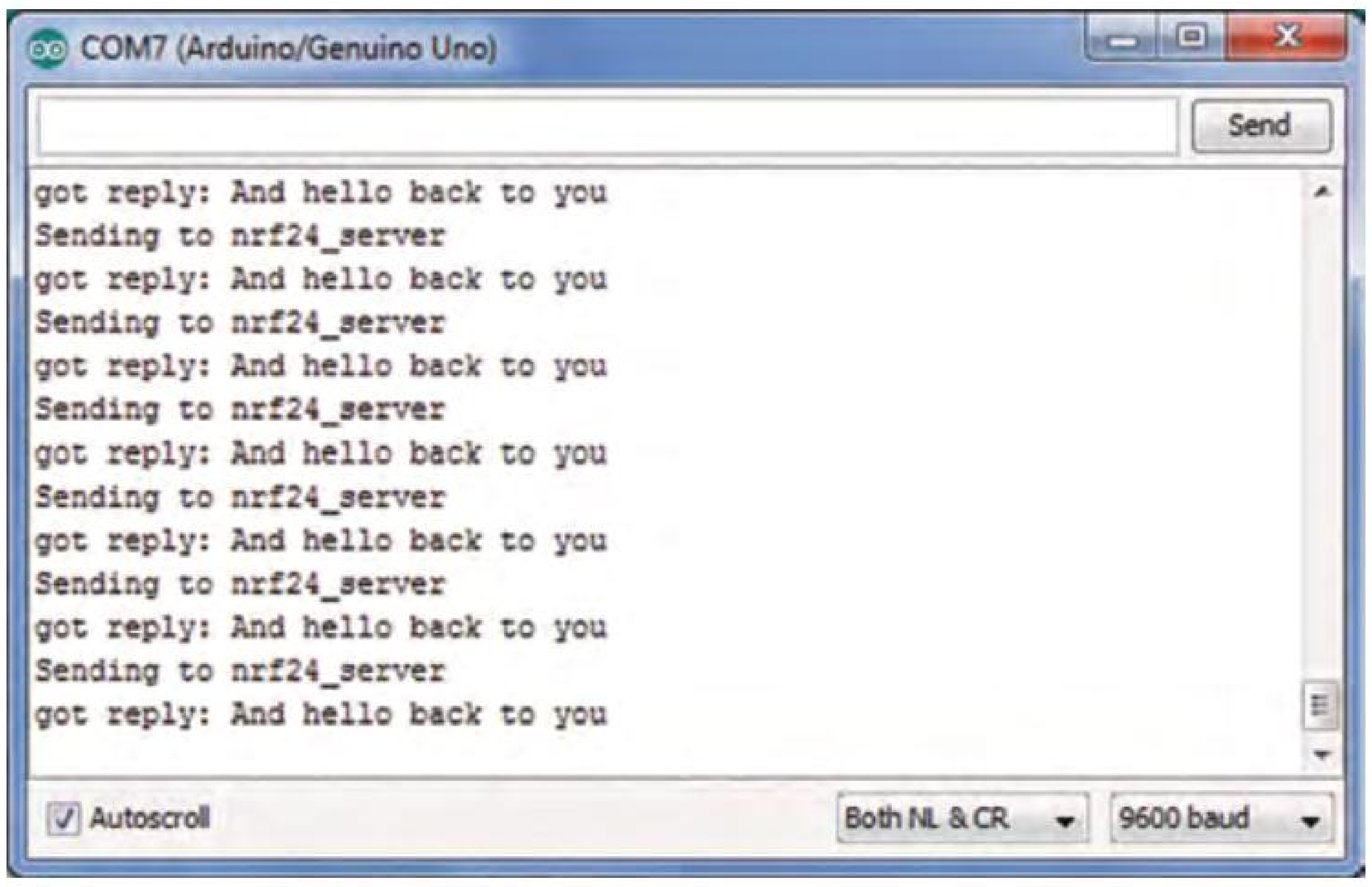
NRF24 libraries

You will need one of the NRF24 libraries (`RF24.h`, `nRFL01.h` or `RH_NRF24.h`) in your code. This should match the chip used in your wireless module. Note that, while several NRF24 libraries are available, we are using the RadioHead library here as this is currently the most recent and comprehensive. Further details of the RadioHead library can be found at: **www.airspayce.com/mikem/arduino/RadioHead/**

Drivers and Managers

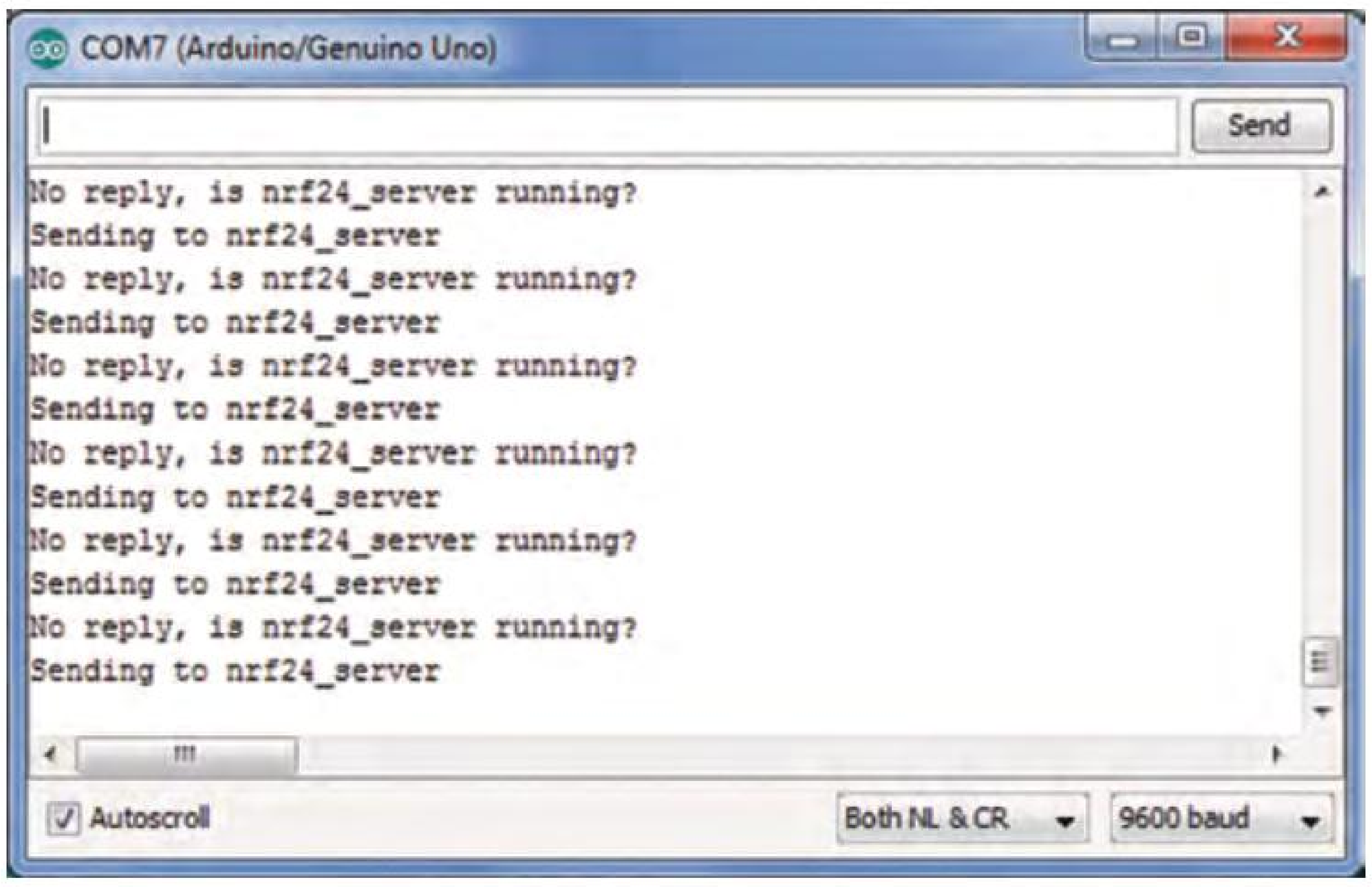
RadioHead consists of two main sets of classes: 'Drivers' and 'Managers'. Drivers provide low-level access to a range of different packet radio chips (and other devices designed for transporting data in packet form) while Managers provide high-level message sending and receiving facilities. RadioHead code will have an instance of a Driver to provide access to the radio (or other transport device) and a Manager that uses the specified driver to send and receive messages for the particular application.

Your code needs to instantiate the Driver and Manager and it also needs to initialise the Manager. The Manager can then be used to send and receive messages like those that you met earlier in *Arduino Workshop*. It is also possible



```
got reply: And hello back to you
Sending to nrf24_server
got reply: And hello back to you
Sending to nrf24_server
got reply: And hello back to you
Sending to nrf24_server
got reply: And hello back to you
Sending to nrf24_server
got reply: And hello back to you
Sending to nrf24_server
got reply: And hello back to you
Sending to nrf24_server
got reply: And hello back to you
```

Fig.6.5. Client serial monitor when data is being received



```
No reply, is nrf24_server running?
Sending to nrf24_server
No reply, is nrf24_server running?
Sending to nrf24_server
No reply, is nrf24_server running?
Sending to nrf24_server
No reply, is nrf24_server running?
Sending to nrf24_server
No reply, is nrf24_server running?
Sending to nrf24_server
No reply, is nrf24_server running?
Sending to nrf24_server
```

Fig.6.6. Client serial monitor when the server is out of range

Table 6.2 SPI implementation in the Arduino Uno

Designation	Function	Direction	Uno pin number
SCLK	Serial clock	Output from Uno	13
MOSI	Master output/slave input	Output from Uno	11
MISO	Master input/slave output	Input to Uno	12
CS/SS	Chip select/slave select	Output from Uno	10
GND	Ground	Common	GND

to use a Driver on its own (ie, without a Manager) although this only allows unaddressed, unreliable data handling using only the basic facilities available from the Driver alone. This very simple form of communication is how we implemented the simple wireless-linked rain alarm featured in this month's *Get Real* project.

Using the NRF24 libraries

The NRF24 libraries are easy to use. For example, to set the RF channel you would use a statement of the form:

```
// Set the nRF24L01 chip to Channel 83
nrf24.setChannel(83);
```

Note that the channel parameter should be a value between 0 and 83. Values outside this range will be outside the approved ISM band in most countries (including the UK) while 66 should be the highest channel used in the USA.

To set the data rate and transmit power you can use a statement like this:

```
// Set the nRF24L01 chip to max. output and max. data rate
nrf24.setRF(RH_NRF24::DataRate2Mbps, RH_
NRF24::TransmitPower0dBm);
```

Note that there are two parameters; one sets the data rate, while the other sets the transmit power. The data rate can take values of 2Mbps, 1Mbps and 250kbps; the transmit power can take values of -18dBm (entered as '18mBm'), -12dBm (entered as 'm12dBm'), -6dBm (entered as 'm6dBm') and 0dBm (entered as '0dBm'). Remember that the term 'dBm' refers to decibels relative to 1mW. Thus 0dBm corresponds to an output power of 1mW, -6dBm corresponds to 0.25mW, -12dBm corresponds to 0.0625mW, and -18dBm corresponds to 0.016mW.

As a further example, to set the data rate to 1Mbps and a transmit power of -6dBm (about 0.25mW) you would use:

```
// Set the nRF24L01 chip to 1Mbps and 0.25mW output
nrf24.setRF(RH_NRF24::DataRate1Mbps, RH_
NRF24::TransmitPowerm6dBm);
```

The chip can be set to transmit or receive mode using statements of the form:

```
// Set the nRF24L01 chip to receive mode
nrf24.setRF(RH_NRF24::setModeRx());
```

```
// Set the nRF24L01 chip to transmit mode
nrf24.setRF(RH_NRF24::setModeTx());
```

To pair a client with a server a shared channel address should be used. The default hexadecimal address is A0A0A0A0A0. To change this, you need to include a line of the form:

```
// Set the address to C2C2C2C2C2 hex.
uint8_t pipe2Address[] = {0xC2, 0xC2, 0xC2,
0xC2, 0xC2};
```

Again, it should go without saying that the same channel, data rate and pipe address should be used for both wireless modules.

Get Real : wireless-linked rain alarm

In this month's *Get Real* we will be describe another useful project in the form of a wireless-linked rain alarm. The project is built in two parts; a sensor and transmitter unit and a receiver and alarm unit. Both units use low-cost Arduino Uno microcontrollers and both units are fitted with low-cost wireless transmitter/receiver modules. This project is an ideal way of understanding how wireless linking can be used to reliably transfer data from one Uno to another at distances of up to 100m.

You will need

Two Arduino Uno microcontrollers
USB Type-A to Type-B cable (for programming only)
Computer with an available powered USB port (for programming only)
2 nRF24L01+ wireless modules (or direct equivalent)
1 rain/water sensor board (see text)
2 SPST switches, S1 and S2
3 330Ω resistors, R1 to R3
1 red LED
1 amber LED
1 green LED
1 piezoelectric sounder (see text)
2 9V batteries (see text), B1
1 stripboard for mounting the LEDs and sounder
1 7-way PCB header
Connecting wires

Sensor/transmitter unit

The complete circuit of the Arduino Uno rain alarm sensor/transmitter is shown in Fig. 6.7. It consists of three modules (the Uno, rain sensor, and wireless module) together with a nominal 9V battery supply. The header connections to the Uno and nRF24L01+ wireless module are shown in Fig. 6.8 and Fig. 6.9 respectively. Interconnections can be made using short male-to-male jumper leads as listed in Table 6.3.

The header markings on the wireless modules can sometimes be a little indistinct (or no markings might be found). Fig.6.10 and Fig.6.11 show the upper and lower sides of a typical high-power wireless module based on the nRF24L01+ chip. In this case, the pin numbers and signals are clearly marked. The orientation of other modules, such as those shown earlier in Fig. 6.1, are invariably similar.

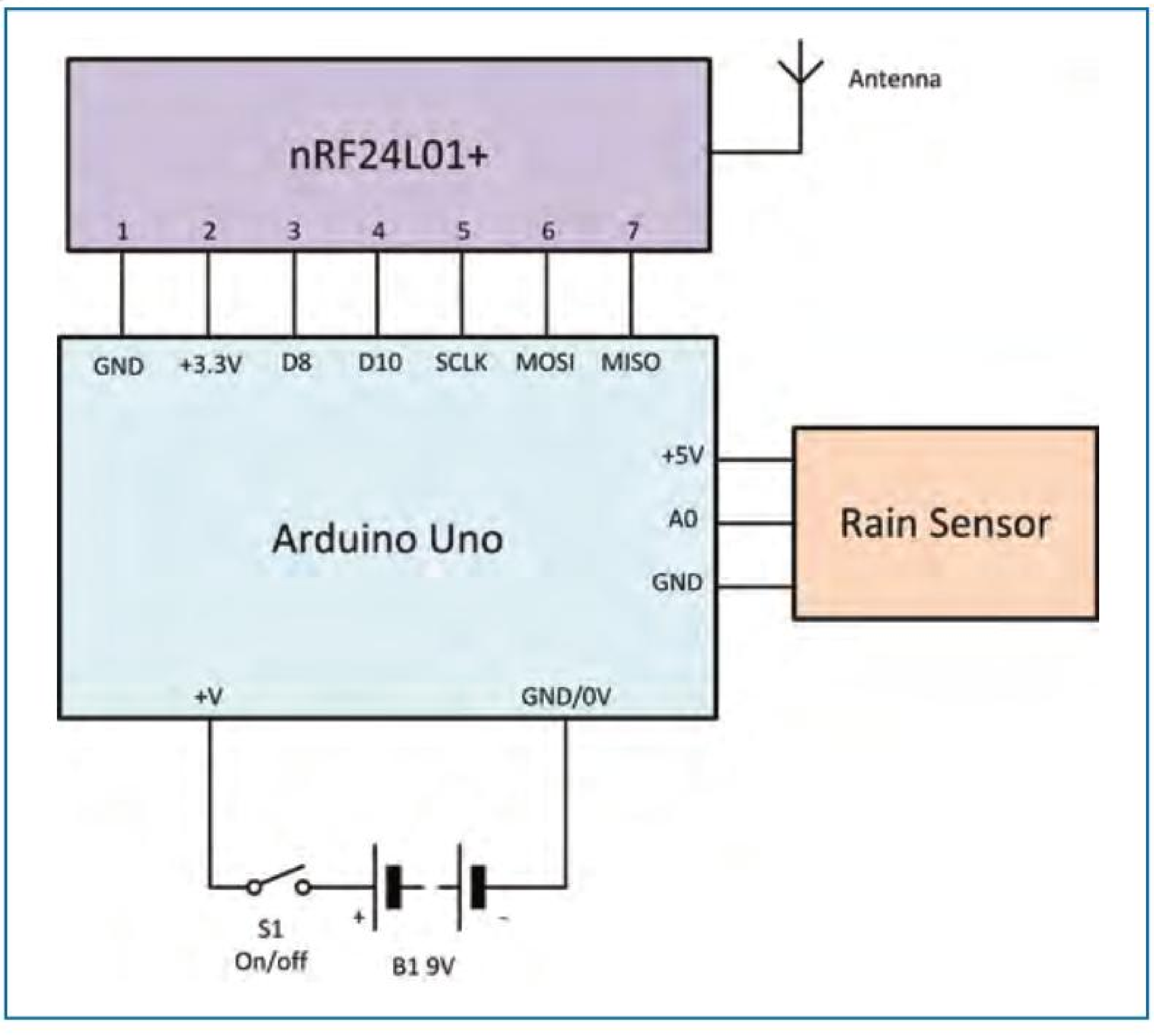


Fig.6.7. Complete Aduino Uno sensor/transmitter unit

Table 6.3 Interconnections for the sensor/transmitter

Arduino Uno		nRF24L01 module	
Pin	**Signal**	**Pin**	**Signal**
Digital 8	CE	3	CE
Digital 10	SS	4	CSn
SPI SCLK	SCLK	5	SCLK
SPI MOSI	MOSI	6	MOSI
SPI MISO	MISO	7	MISO
Power 3.3V	+3.3V	2	3.3V
Power GND	GND	1	GND

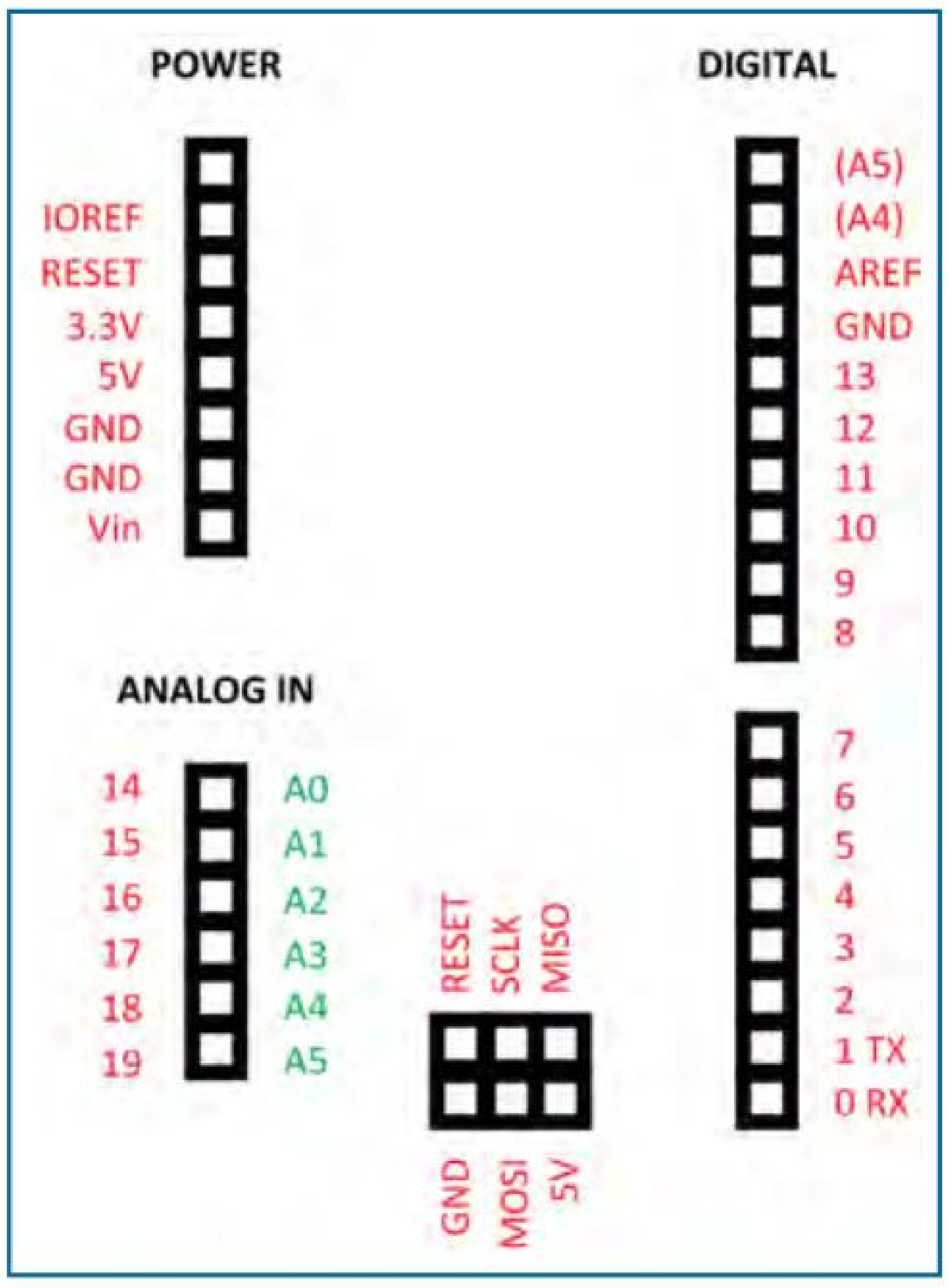


Fig.6.8. Uno header connections

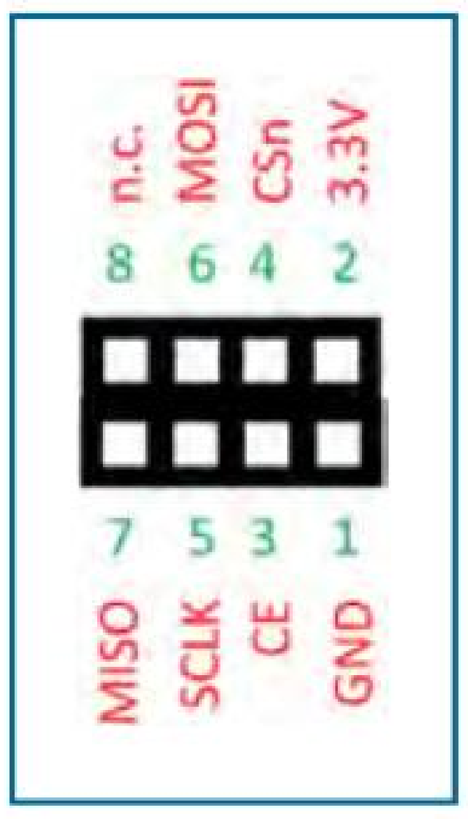


Fig.6.9. nRF24L01+ header connections

Rain sensor

The rain sensor can be based on an ultra-low-cost module like that shown in Fig. 6.12. These are available from several suppliers, including eBay for less than £1. The module senses the resistance between parallel conducting strips. This resistance is converted to an analogue voltage which is fed to the Uno's A0 analogue input. The rain sensor requires a +5V supply and ground. A more sensitive version which incorporates a comparator and has both analogue and digital outputs is shown in Fig. 6.13.

Receiver/alarm unit

The complete circuit of the Arduino Uno rain alarm receiver/alarm unit is shown in Fig.6.14. This consists of three modules (the Uno, alarm/indicator board and wireless module) together with a nominal 9V battery supply. The three LED indicators and their series resistors, along with the piezoelectric sounder can be assembled on a small piece of stripboard and linked to the Uno by five connecting wires (including a ground connection). The connections to the wireless module are exactly the same as those described earlier and listed in Table 6.3. Fig.6.15 shows our breadboard test arrangement. Note that the piezoelectric sounder must be a DC-operated device.

Code

The sensor/transmitter and receiver/alarm units require different code. Listing 6.2 shows the complete code for the sensor/transmitter unit, while Listing 6.3 shows the complete code for the receiver/alarm unit. As usual, we've included numerous comments in the code to help you understand what's happening.

The code requires two libraries; `SPI.h` and `RH_NRF24.h`. The first of these provide functions that facilitate the use of the SPI link from the Uno to the wireless module. The second provides the functions associated with controlling the nRF24L01. The RH_NRF24 library is available from Github (as mentioned earlier).

Notice that in Listing 6.2 and 6.3 we've set the channel number to 1 (corresponding to an operating frequency of 2.401GHz). However, you might wish to check local Wi-Fi activity

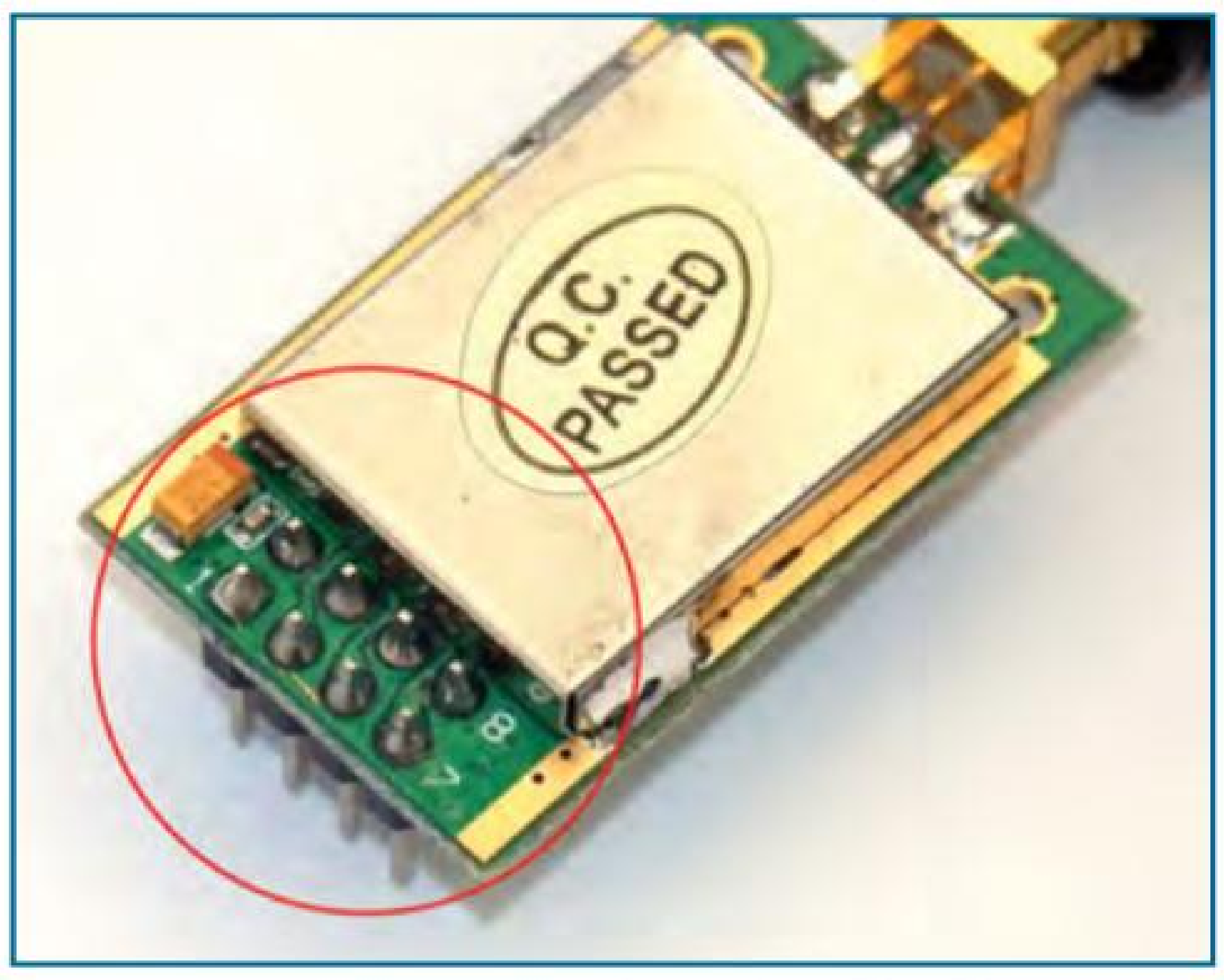


Fig.6.10. Upper side of a high-power nRF24L01+ wireless module with numbered header pins

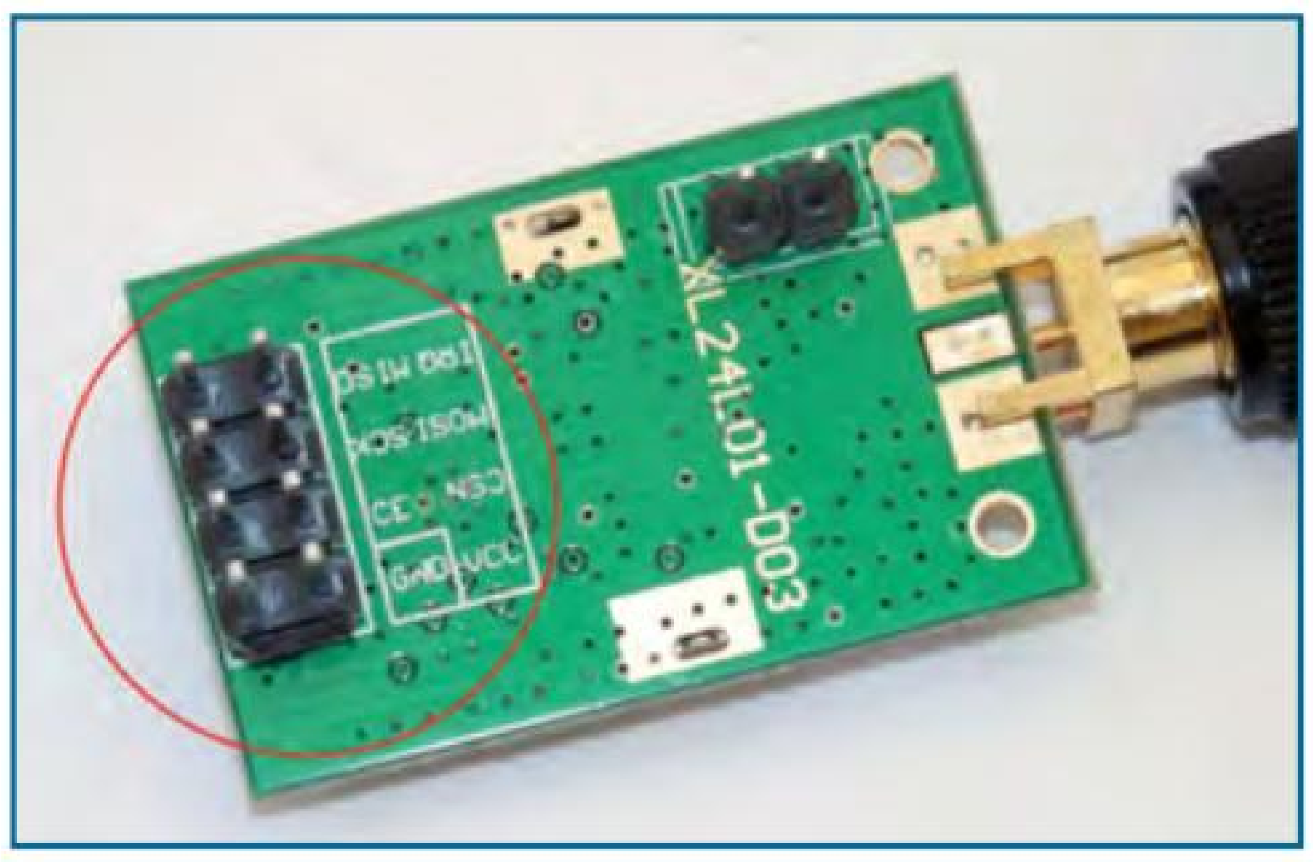


Fig.6.11. Lower side of a high-power nRF24L01+ wireless module with signals marked

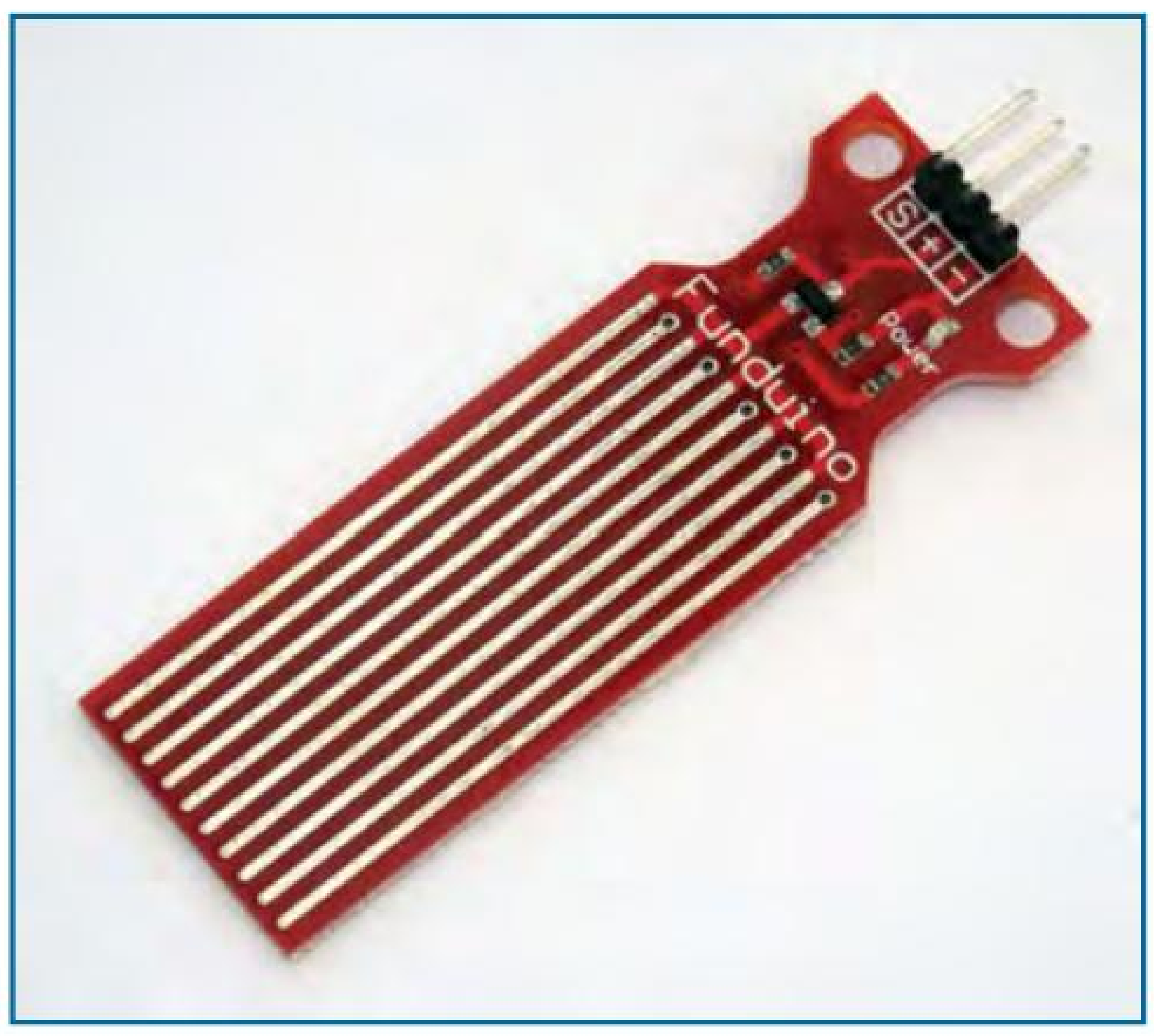


Fig.6.12. Low-cost rain sensor module

Listing 6.2 Code for the sensor/transmitter unit

```
// Rain alarm transmitter using NRF24 module

#include <SPI.h>
#include <RH_NRF24.h>
t
RH_NRF24 nrf24;

void setup()
{
   nrf24.init();
   nrf24.setChannel(1);
   nrf24.setRF(RH_NRF24::DataRate2Mbps, RH_NRF24::TransmitPower0dBm);
}

void loop()
{
    // Get the analogue input voltage
    int sensorValue = analogRead(A0);
    // and send it using the NRF24 radio module
    byte data[4]; // four byte data package
    data[0] = {(sensorValue >> 8) & 0xFF};
    data[1] = {sensorValue & 0xFF};
    nrf24.send(data, sizeof(data));
    delay(2000);
}
```

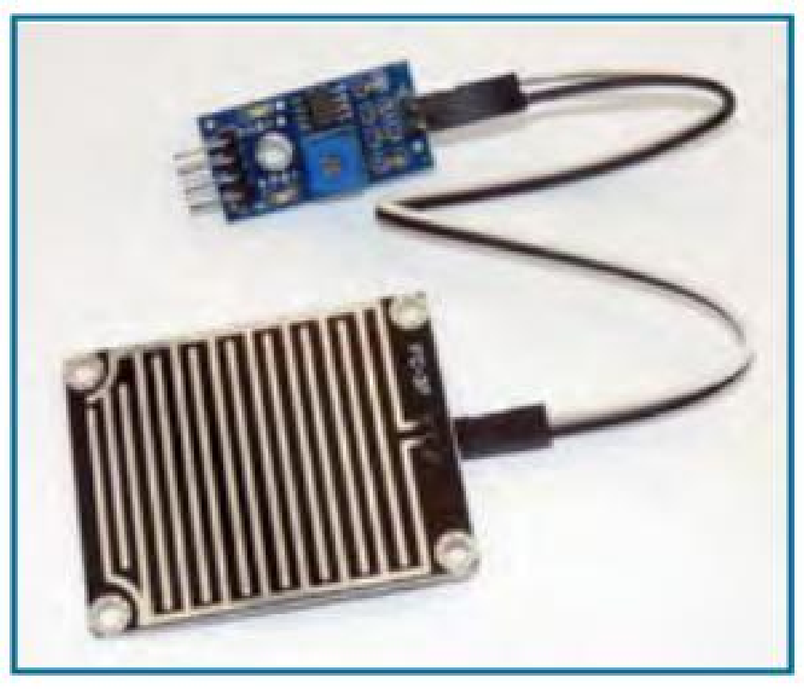


Fig.6.13. Low-cost rain sensor module with both analogue and digital outputs

Listing 6.3 Code for the receiver/alarm unit

```
// Rain alarm receiver using NRF24 module

#include <SPI.h>
#include <RH_NRF24.h>

int ut = 410; // upper threshold
int lt = 120; // lower threshold
int green = 2;  // green LED is on D2
int amber = 3;  // amber LED is on D3
int red = 4;  // red LED is on D4
int alarm = 5; // sounder is on D5
int sensorReceived; // analogue value

RH_NRF24 nrf24;

void setup()
{
  // Initialise and set up NRF24 module
  nrf24.init();
  nrf24.setChannel(1);
  nrf24.setRF(RH_NRF24::DataRate2Mbps, RH_NRF24::TransmitPower0dBm);
  // set up digital outputs
  pinMode(green, OUTPUT);
  pinMode(amber, OUTPUT);
  pinMode(red, OUTPUT);
  pinMode(alarm, OUTPUT);
}

void loop()
{
  byte buf[RH_NRF24_MAX_MESSAGE_LEN];
  byte len = sizeof(buf);

  if (nrf24.waitAvailableTimeout(500))
  {
    // Check for message data
    if (nrf24.recv(buf, &len))
    {
      sensorReceived = (buf[0]<<8)+ buf[1];
    }
  }
  delay(400);
  if (sensorReceived < lt) // Green ON
  {
    digitalWrite(green, HIGH);
    digitalWrite(amber, LOW);
    digitalWrite(red, LOW);
    digitalWrite(alarm, LOW);
  }
  else if (sensorReceived >= ut) // Red and alarm ON
  {
    digitalWrite(green, LOW);
    digitalWrite(amber, LOW);
    digitalWrite(red, HIGH);
    digitalWrite(alarm, HIGH);
  }
  else // Amber ON
  {
    digitalWrite(green, LOW);
    digitalWrite(amber, HIGH);
    digitalWrite(red, LOW);
    digitalWrite(alarm, LOW);
  }
}
```

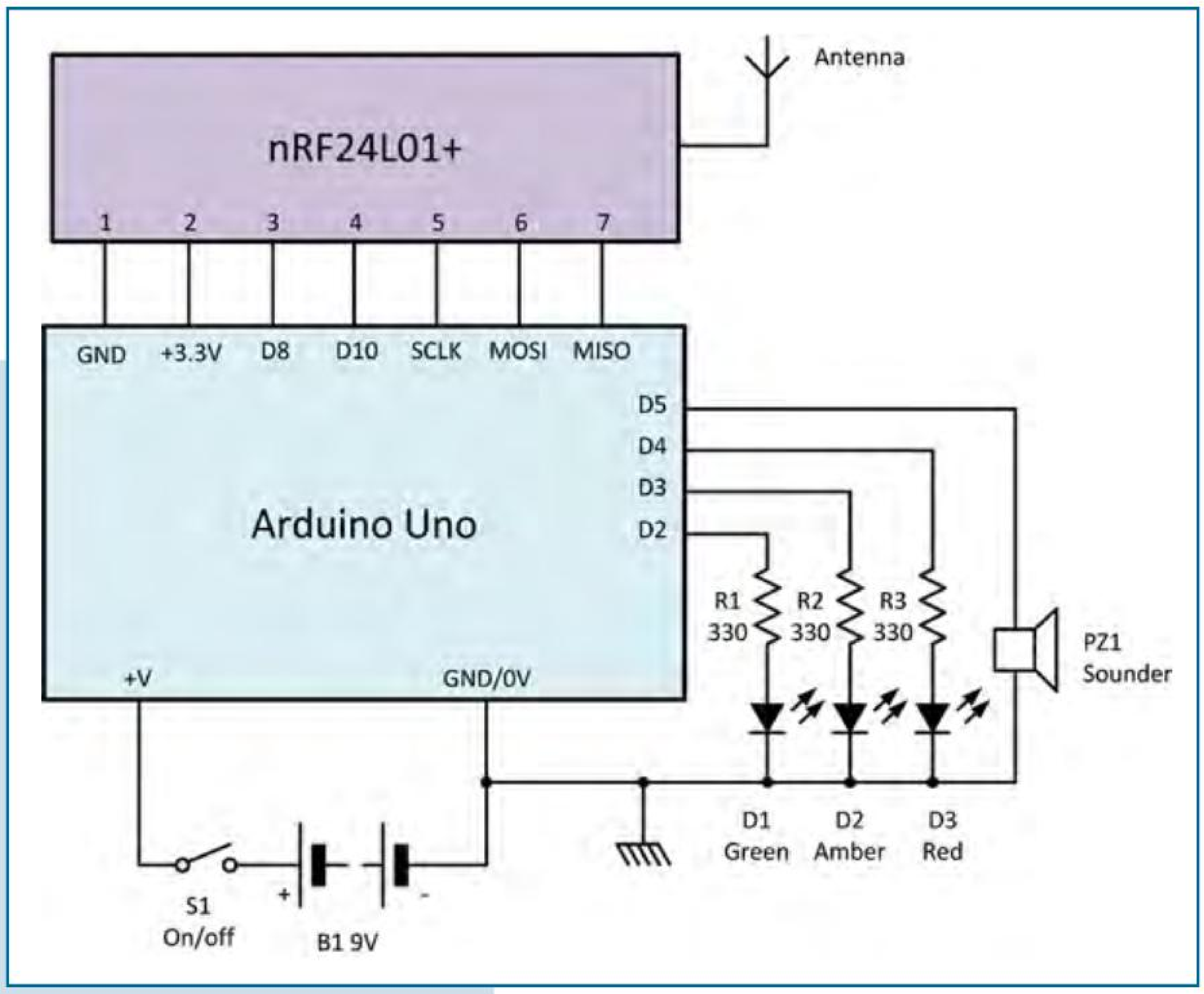


Fig.6.14. Complete circuit of the Arduino Uno receiver/alarm unit

before you finally decide which channel to use. To do this, you can use one of several applications which will analyse Wi-Fi usage in your locality. Fig.6.16 shows the local Wi-Fi usage when we tested our wireless linked rain alarm using the popular (and free) Acrylic package. From this, we concluded that a better choice of channel would have been around 2.425GHz (ie, channel 25) as this falls neatly in the gap between Wi-Fi channels 3 and 4.

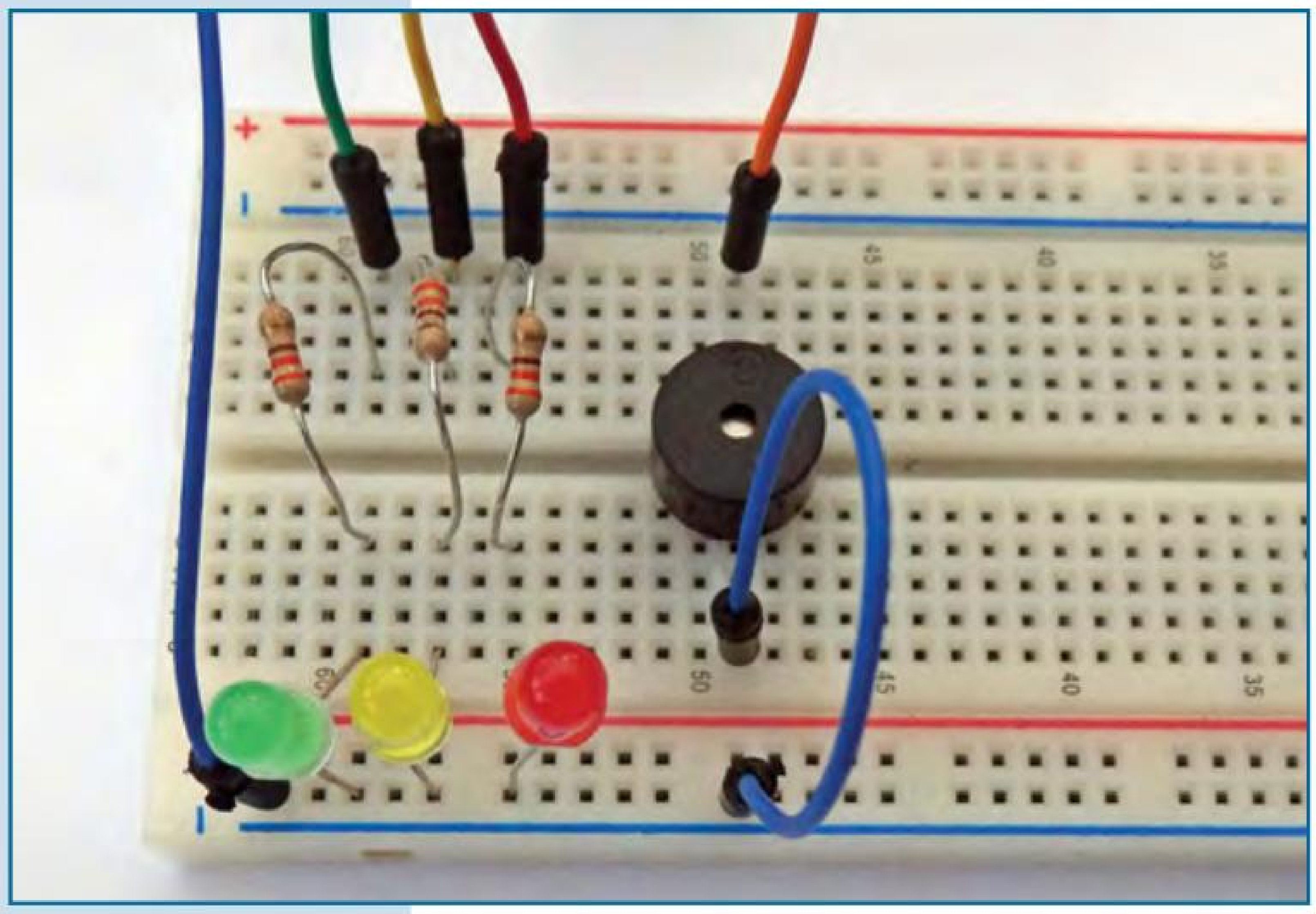
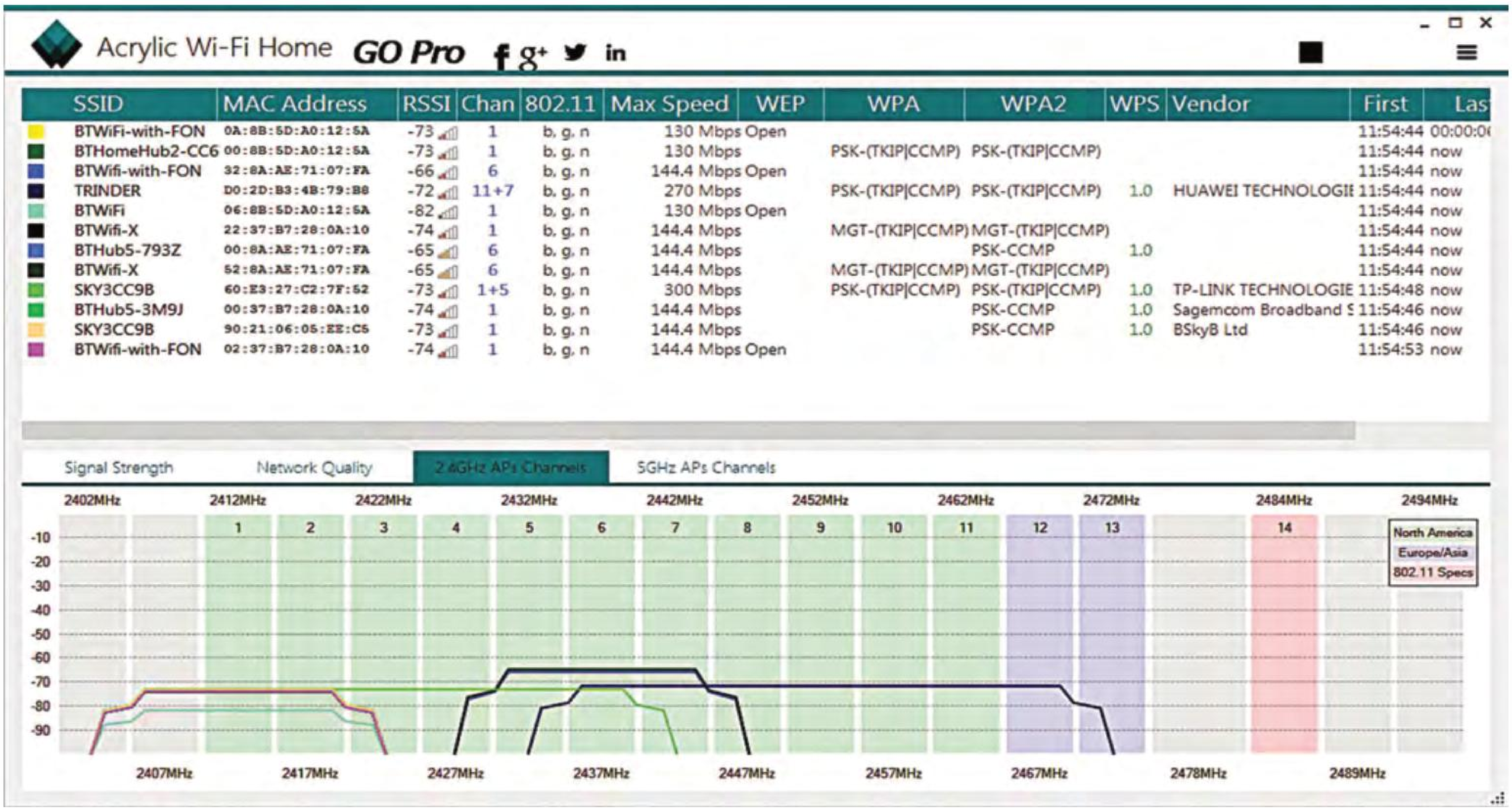


Fig.6.15. Breadboard test arrangement of the receiver/alarm

In Listing 6.3 you might also wish to experiment with the upper and lower sensing thresholds. With the values indicated (410 and 120) the red LED became illuminated with a steady drizzle present, while the amber LED became illuminated when just a few spots of rain appear. Some experimentation might be necessary to find the right values for your rain sensor.

As with all of our *Get Real* projects, the code should first be entered into the IDE and then saved before compiling and uploading it to the Uno as described in last month's *Arduino Workshop*. When you have debugged and corrected your



	SSID	MAC Address	RSSI	Chan	802.11	Max Speed	WEP	WPA	WPA2	WPS	Vendor	First	Las
🟨	BTWiFi-with-FON	0A:8B:5D:A0:12:5A	-73	1	b, g, n	130 Mbps	Open					11:54:44	00:00:0
🟩	BTHomeHub2-CC6	00:8B:5D:A0:12:5A	-73	1	b, g, n	130 Mbps		PSK-(TKIP|CCMP)	PSK-(TKIP|CCMP)			11:54:44	now
🟦	BTWifi-with-FON	32:8A:AE:71:07:FA	-66	6	b, g, n	144.4 Mbps	Open					11:54:44	now
⬛	TRINDER	D0:2D:B3:4B:79:B8	-72	11+7	b, g, n	270 Mbps		PSK-(TKIP|CCMP)	PSK-(TKIP|CCMP)	1.0	HUAWEI TECHNOLOGIE	11:54:44	now
🟩	BTWiFi	06:8B:5D:A0:12:5A	-82	1	b, g, n	130 Mbps	Open					11:54:44	now
⬛	BTWifi-X	22:37:B7:28:0A:10	-74	1	b, g, n	144.4 Mbps		MGT-(TKIP|CCMP)	MGT-(TKIP|CCMP)			11:54:44	now
🟦	BTHub5-793Z	00:8A:AE:71:07:FA	-65	6	b, g, n	144.4 Mbps			PSK-CCMP	1.0		11:54:44	now
⬛	BTWifi-X	52:8A:AE:71:07:FA	-65	6	b, g, n	144.4 Mbps		MGT-(TKIP|CCMP)	MGT-(TKIP|CCMP)			11:54:44	now
🟩	SKY3CC9B	60:E3:27:C2:7F:52	-73	1+5	b, g, n	300 Mbps		PSK-(TKIP|CCMP)	PSK-(TKIP|CCMP)	1.0	TP-LINK TECHNOLOGIE	11:54:48	now
🟩	BTHub5-3M9J	00:37:B7:28:0A:10	-74	1	b, g, n	144.4 Mbps			PSK-CCMP	1.0	Sagemcom Broadband	11:54:46	now
🟧	SKY3CC9B	90:21:06:05:EE:C5	-73	1	b, g, n	144.4 Mbps			PSK-CCMP	1.0	BSkyB Ltd	11:54:46	now
🟪	BTWifi-with-FON	02:37:B7:28:0A:10	-74	1	b, g, n	144.4 Mbps	Open					11:54:53	now

Fig.6.16. Using the Acrylic Wi-Fi analyser (note the gap between Wi-Fi channels 3 and 4)

code don't forget to save it by clicking on 'File' and 'Save' or 'Save As…'. Next click on 'Sketch' and 'Verify/Compile'. Any compilation errors will then be reported in the window at the bottom of the IDE. Don't forget that, if they are not already present, you may need to add library files using the IDE's File Manager. The procedure for adding and managing library files was described in *Part Three* of *Teach-In 2016*.

Next month

In next month's *Teach-In 2016 Arduino World* we'll look at the Arduino Uno's diminutive cousin, the Arduino Nano. This tiny microcontroller provides you with a cost-effective alternative to the Uno that's small enough to be tucked away into an extremely compact space. *Arduino Workshop* will introduce you to infrared motion sensors, while our programming feature, *Coding Quickstart*, introduces tone generation techniques. Finally, *Get Real* will describe the design and construction of a simple Arduino Nano-based PIR intruder detector.

HP 34401A Digital
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HP 54600B Oscilloscope Analogue/Digital
Dual Trace 100MHZ

MARCONI 2955B Radio
Communications Test Set

FLUKE/PHILIPS PM3092 Oscilloscope
2+2 Channel 200MHZ Delay TB, Autoset etc

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NET WORK

by Alan Winstanley

Virtually there

LAST month's *Net Work* delved into Google Cardboard, the world of virtual reality that can be experienced using a compatible viewer along with a suitable smartphone. The cheap and cheerful Cardboard Viewer shown last month works like a simple visor that lets you view a split-screen VR movie or app, immersing yourself in a virtual world that you can navigate around by turning your head or bobbing around. Your phone's accelerometers do the rest. The Cardboard V2 viewer is suitable for larger smartphones up to 6-inch screen size; a simple switch, like a camera shutter, gently taps the screen to access menu functions such as moving to the next waypoint in Google Street View.

Cardboard gives you an idea of what can be achieved with VR apps at very low cost using smartphone displays, but the floaty and occasional queasy feeling will not suit everyone, and any inherent display lag can add to a feeling of nausea. Nevertheless, it's fun to have a go. However, there are alternatives to a semi-disposable cardboard viewer, more substantial plastic ones that do the same job appear all over the web. A common one is the 'VR Box 2' virtual reality glasses, a purposeful-looking but slightly contraption-like device that is well padded and has an adjustable elastic headband. As a plus point, its two lenses are independently adjustable for focus and IPD (interpupillary distance); Google Cardboard V2's own specification is fixed at 64mm IPD (which I found coincides with the mean distance of 64.7mm shown in a 1988 US Army survey of personnel, see: **https://en.wikipedia.org/wiki/Interpupillary_distance**).

VR BOX
VIRTUAL REALITY GLASSES

The VR Box 2 VR viewer can be bought online for a target price of £10-£15: get a bundled Bluetooth mini gamepad too

The VR Box 2 is adjustable to better suit an individual's vision; the user's smartphone clamps into an expanding plastic holder that slides into place from the side. Exit holes for headphone cables are provided, and the front panel can be slid open to expose the phone's camera if needed.

The VR Box 2 viewer works well enough. Since a screen-tapping button isn't available, the test sample, sourced from China, included a Bluetooth mini gamepad keyfob instead. The tiny rechargeable thumb-sized gamepad was 'discovered' immediately by the author's Android phone (it also claims to be iOS compatible) and it can perform various basic operations by remote control.

Some promising-looking VR apps from Google Play Store proved to be disappointing, or they might work better on newer smartphones. Readers could start with demos of VR Cave and VR Cave Flythrough, or wander around Egypt Chamber which needs a mini gamepad. For a very modest outlay the VR Box 2 lets you delve more deeply into virtual reality before you invest in any apps, and it can be had for about £15 from Chinese suppliers such as Aliexpress or Banggood, and Bluetooth gamepad controllers are often bundled as well.

Of course, none of these low-cost units compares with high-end VR gaming systems such as the new Oculus Rift, (see **www.oculus.com** for some demos) which are expensive headset VR visors with displays, optics and audio optimised for enthusiasts to connect to a powerful gaming PC. Oculus is now owned by Facebook, which pumped $2 *billion* into the deal two years ago. Additional controllers (wired or wireless) provide more user input to allow the wearer to participate in the VR experience.

Too much of a good thing

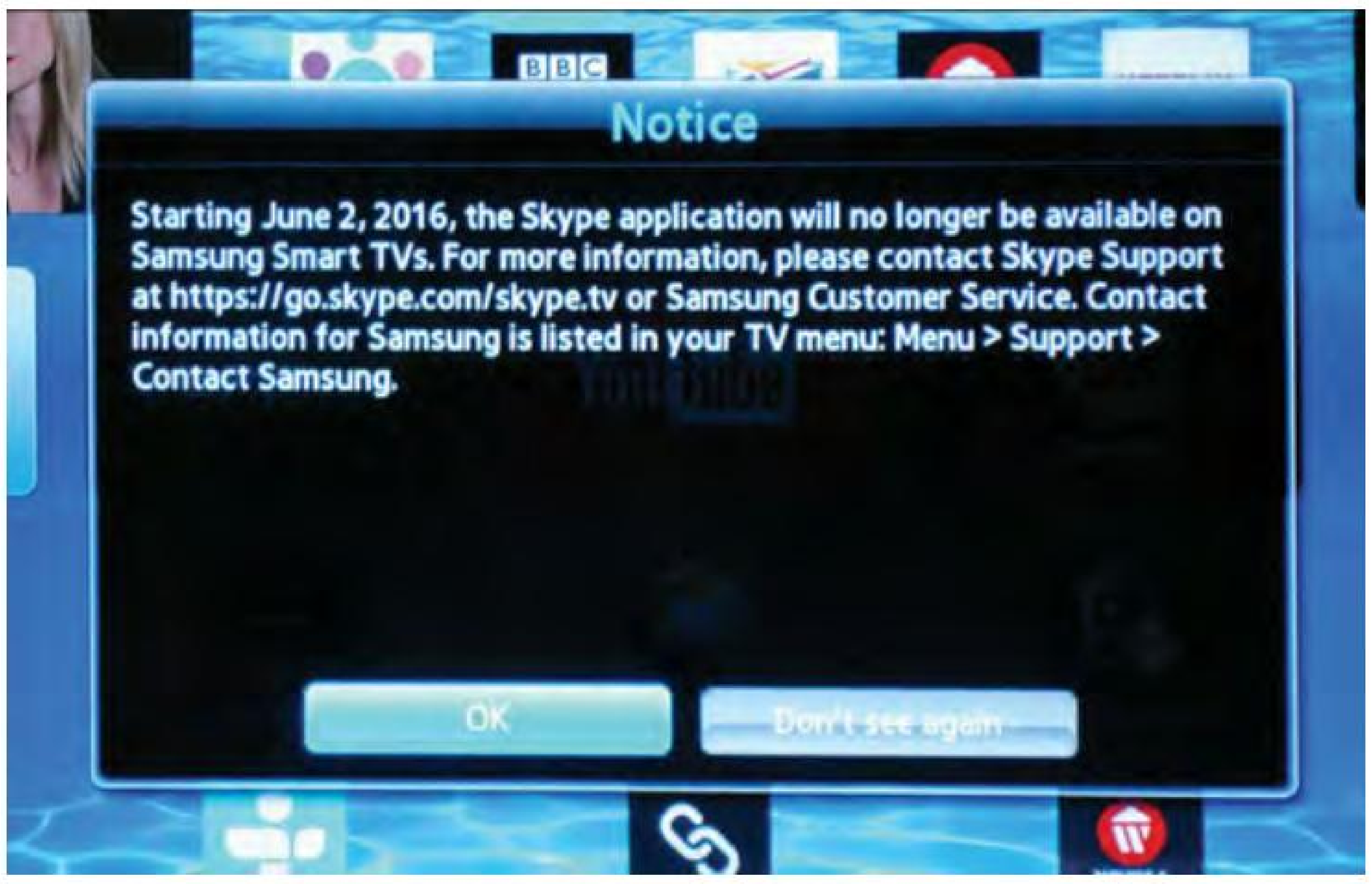
Facebook's Mark Zuckerberg wrote two years ago that, apart from games, they aim to make Oculus a virtual reality platform for other experiences. 'Imagine enjoying a court side seat at a game, studying in a classroom of students and teachers all over the world or consulting with a doctor face-to-face – just by putting on goggles in your home. By feeling truly present, you can share unbounded spaces and experiences with the people in your life. Imagine sharing not just moments with your friends online, but entire experiences and adventures,' the multi-billionaire mused.

There is a feeling of *déjà vu* about big brands wanting to enhance our online 'experience' in this way. Although virtual reality applications have a role to play in areas other than in gaming, possibly in watching movies, or medicine, training or education, I am not sure that many users will routinely don some VR goggles and immerse themselves in a virtual environment for everyday tasks like shopping or consulting a doctor. Recent history proves that we prefer to shelter behind email or leave messages for somebody to answer. For many users, the idea of using 'Live Chat' – hesitant, terminal-style comms like ICQ of the 1990s – is a bit invasive, impersonal and challenging enough, but it is becoming more widespread as the simplest and cheapest way of talking to a company online (or 'reaching out' to them, as they call it these days).

Facebook weren't the first to splurge a couple of billion on what they thought would be the next sure bet; more than a decade earlier eBay paid the same sort of money ($2.6 billion in cash and shares) to buy the loss-making VoIP startup Skype, before selling off a majority shareholding in 2009 for $1.9 billion. Possibly the youngbeards of eBay thought that buyers and sellers would love to Skype each other, messaging or using their webcams, and chatter excitedly about the merchandise being sold on eBay's online market stalls. If that was the idea, it never took off: ordinary email and eBay's own messaging system were good enough for what buyers and sellers wanted to do, which was to keep things unobtrusively at arm's length. Skype did, however, garner a large number of subscribers who gladly paid hard cash for this IP-based telecoms service and many users and businesses depend on VoIP services like Skype to communicate across the world. Microsoft then bought Skype outright in 2011 for $8.5 billion in cash. Several years earlier in 2008, Microsoft had bought Danger Inc for an estimated $500 million, in an effort to develop mobile phone social networking devices such as Microsoft Kin (**https://en.wikipedia.org/wiki/Microsoft_Kin**), a trendy Blackberry-like unit that Microsoft swiftly killed off at birth. For about one-tenth of the price ($50 million), Google had bought a secretive little outfit called Android in 2005, with the first Android mobile phone launching some two years later – the rest is history.

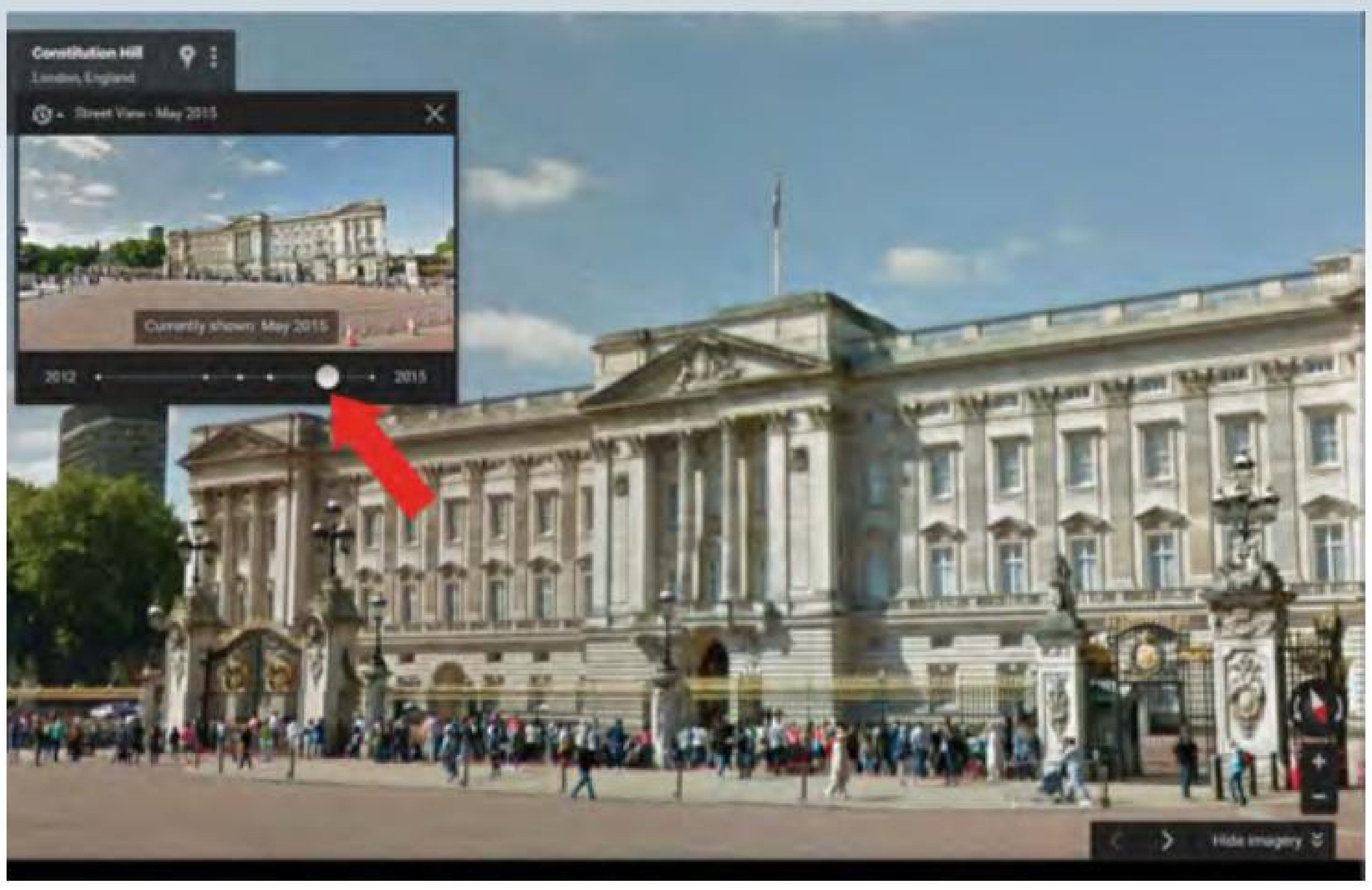
Some of the remarkable developments in the world of virtual reality hold much promise. HTC is known for its quality mobile phones but the new $800/ (£750 in the UK) HTC Vive (**www.htcvive.com**) is a VR headset that hooks to a PC and actually lets you walk around a virtual world, translating your movements into gameplay itself – if you have the space! A fun example is shown in the *Fantastic Contraption* demo on YouTube at **https://youtu.be/2JRmZdurBaA.** Try the amazing *Apollo 11 VR Moon Landing* (for Rift, Vive, PS4) demo'd by a Vive player at **https://www.youtube.com/watch?v=kVP2aN2JMgk** (contains language). Anyone who has played tennis on a Nintendo Wii will know how dangerous thrashing limbs around in mid air can be, so the HTC Vive visor supposedly warns users before they collide into a wall. Time will tell how effective it is, but Expect to hear more about HTC Vive and Oculus Rift as VR technology evolves. A cheaper option (£350) for many may be Sony's PlayStation VR, which will run with a PlayStation 4. This should arrive in time for the Christmas market, along with a slew of appealing PS4 games..

As another example of a technological U-turn, Microsoft has recently decided to pull the plug on the Skype app for Smart TVs, a move that will infuriate those who bought a Skype-compatible camera for their Samsung Smart TV, for example. The move is entirely our fault, as we are not using Smart TVs enough and instead we're using always-on tablets and smartphones for Skype, WhatsApp, Facebook Messenger and other networking apps. The author's Samsung Smart TV suffers from interminable updates and the latest ones installed a whole raft of unwanted apps that had to be laboriously un-installed again, and then a pop-up announced that Samsung was killing off Skype. One must be grateful, these days, that a Smart TV still works at all.



Starting June 2, 2016, the Skype application will no longer be available on Samsung Smart TVs. For more information, please contact Skype Support at https://go.skype.com/skype.tv or Samsung Customer Service. Contact information for Samsung is listed in your TV menu: Menu > Support > Contact Samsung.

Microsoft is pulling the plug on Skype support for Smart TVs



Google Street View has a timeline that lets you wind the clock back to earlier snapshots

The map ahead

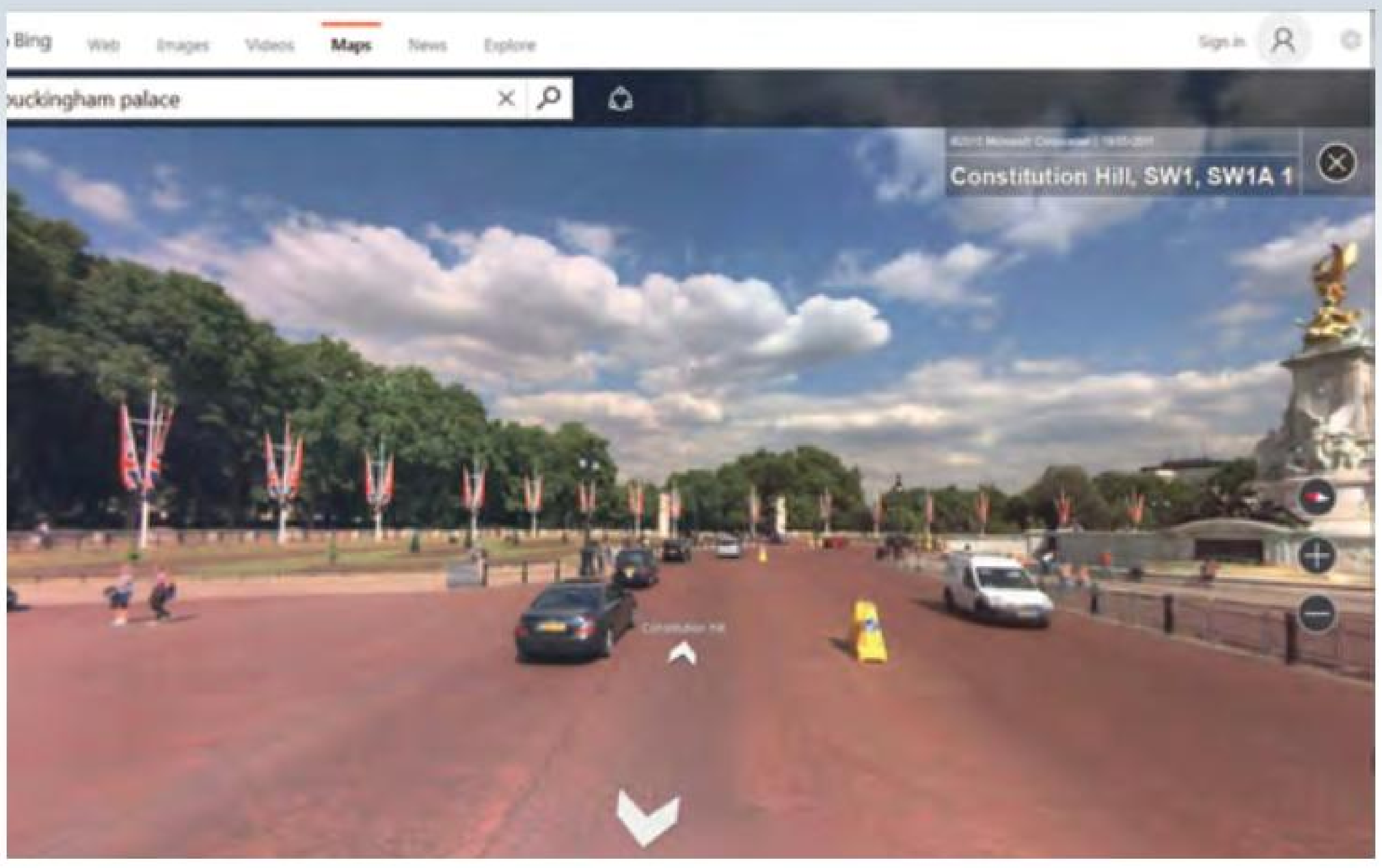
After a rocky and controversial introduction, Google Maps has become an indispensable tool for navigating, tracking, surveying or just plain snooping around a neighbourhood. It's a prime example of Google doing something because it can, with software that reads car licence plates or recognises human faces being used to blur out the details leaving Google Maps' panoramic views laid bare and open to all. It's interesting how in a few short years, many seem to have accepted this form of public 'intrusion' into their own little personal space with a shrug. Integrating local business details and reviews, bus timetables, route planning, satellite and 3D views has turned Google Maps into an encyclopaedic resource of local information, and of course Google Street View is cemented into every estate agent's (realtor's) websites to give inquisitive onlookers an instant feel of a property's surroundings.

Since its first fleet of camera cars trawled our roads and streets, Google has re-visited many areas several times and Google Maps has built up an unsurpassable lead in recording the progression of our street scenery for posterity. In many locations on Street View you can now wind the clock back three or four times to see how the landscape has fared over the years. This can be a little thought-provoking, and in my case I was saddened to see how a familiar old farmhouse nearby has been swept away by the scourge of modern housing.

As an alternative to Google Maps, Microsoft offers Bing Maps instead, which originated from Nokia Maps (briefly called Ovi for a time). Nokia sold it to an automotive consortium at the end of last year and it can be tried at: **www.bing.com/maps/.** Look carefully and you will see '©2016 HERE', 'Here' being the Audi/ BMW/ Daimler group providing this wide-ranging navigational, traffic data and mapping service (**www.here.com**). You can find mobile apps for HERE Maps for Android and Apple in the usual app stores. Bing's answer to Google Street View, called 'Streetside', is a long way behind Google and only covers a fraction of the country, but it has some nice touches, such as moving forwards automatically when you keep the mouse button pressed: no more mindless clicking or tapping to step down the road.

Dashcam dilemma

Regular readers might remember my tests (*Net Work*, January 2015) using a Bluetooth transmitter module connected to my car's OBDII diagnostics socket. Using the excellent Torque app on my smartphone I managed to display and capture the car's engine management data and I could then export the journey into Google Earth. As another example of how online mapping services can be utilised, after witnessing a nasty hit and run traffic collision



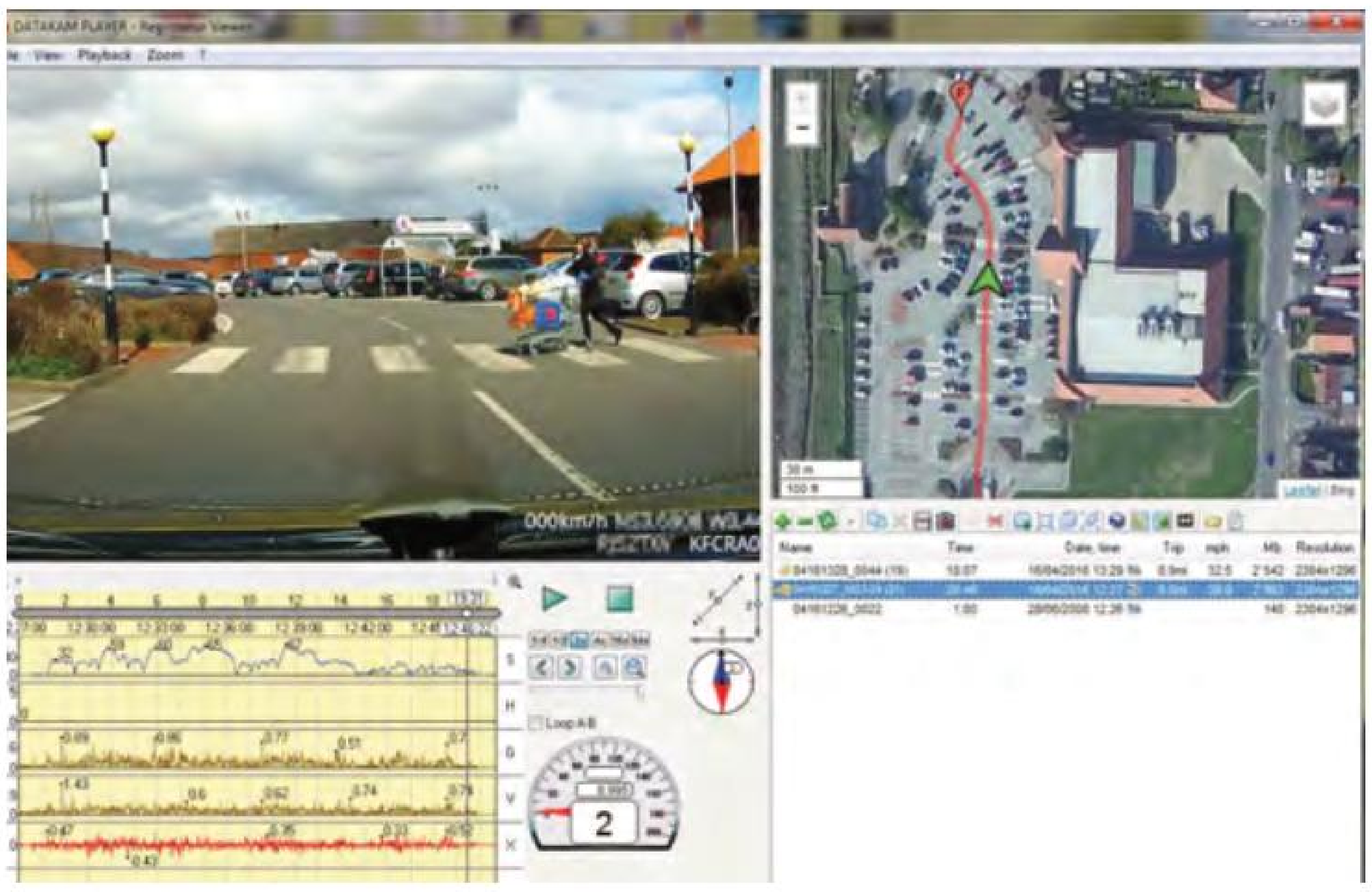
Microsoft's Bing Streetside has much less coverage than Street View – hold down the mouse button to step through the scene automatically

I finally invested in a car dashcam with a GPS module (the K&F Concept Super HD 1296P 2.7-inch). These in-car video recorders are all the rage in Russia and mine had a choice of Russian or English menus. It installed easily enough using its extra-long power supply lead. Recording a car journey results in a string of minute-long .MOV files and GPS data recorded onto a high-speed TF memory card. The movies can be viewed on a Windows PC using specialist software to compile the data and display the footage. Additionally, the software integrates a mapping program (Google Maps only, initially, in this case), which synchronises the car's position with a satellite or moving map view, so you can view your journey progress on-screen back at home.

Unfortunately, the OEM software supplied had problems handling Google Maps, producing a string of script error messages that made the software lock up. There was no workaround for this, but before giving up I had a stroke of luck: searching online I found an excellent alternative dashcam program (Datakam Player, also known as Registrator Viewer) that proved compatible with my camera's files. This was a real bonus because it offered Bing Maps, Open Maps and others, as well as Google Maps, which worked perfectly. It also handled multiple .MOV files intelligently, stitching them together seamlessly and offering freeze-frame, slow motion, fast forward and exporting movie clips. After selecting Google Street View mode, though, the same error messages seen earlier soon popped up, which suggests something has changed with Google's integration that causes dashcam programs like these to crash. Problems were eliminated by returning to Bing Hybrid and other maps. Other promising-looking software, such as Dashcam Viewer V2 stubbornly refused to work with my camera at all though.

More vehicle data, such as speed and G-force is available, so that in the event of collision the latest files are write-protected and the vehicle's general physics is also recorded. The software displays compass bearing, speed and G-force, and its microphone (switchable) captures in-car audio. Movies can also be exported using, for example, Windows Movie Maker, to compress them sufficiently to upload onto Facebook, a lengthy process that worked well in practice. A single, one-minute .MOV file was under 150kB filesize, so a 64GB TF card should hold up to eight hours of high-resolution footage.

This camera and others is available via Amazon (B01AJH8BWM). The final version of Datakam Player was V6.0.0.8 and at the time of writing it is still available free from **http://bit.ly/1Tez5ci**. This will download the .exe directly from **Mediafire.com**, so ignore the popup warning. Simply copy and run the .exe as no installer is needed, then point to your USB memory reader. Sadly, the software's talented Russian designer, Vadim Kozlov, reportedly died in a motor accident last year. More dash camera sellers are bundling this excellent free program and many users, including the writer will appreciate his work for a long time to come. With evidence that Google Maps is already creating problems for dashcam software designers, it is to be hoped that integration with other online maps remains intact for the foreseeable future – let's hope so.



Datakam Player is better than some bundled dashcam software, and offers Bing, Google Maps, Open maps and others for viewing a journey recorded using a dashcam with GPS

Happy birthday

Next month, *EPE* celebrates no less than twenty years of Net Work, so we will hark back to earlier times and maybe speculate about what the exciting world of Internet technology still has in store. You can email me at **alan@epemag.demon.co.uk**, or send your feedback to the editor at: **editorial@wimborne.co.uk**. See you next month for this column's 20th birthday!

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PIC n' Mix

Mike O'Keeffe

Our periodic column for PIC programming enlightenment

PICs and the PICkit 3: A beginner's guide – Part 2

LAST MONTH, we started this beginner's guide to PICs and the PICkit3 with a look at the differences between microcontrollers and microprocessors, and to illustrate this we compared the Raspberry Pi and Arduino with PICs. I concluded that – in my opinion(!) – although PICs are not necessarily the simplest or quickest device to use, they are the most flexible and powerful control route.

I strongly recommend you re-read last month's *PIC n' Mix* before moving on to this article. In that piece I touched upon Microchip's MPLAB X integrated development environment (IDE). I really wanted to tackle this on its own because it is a huge program – it can be your worst enemy or your best friend. So let's take it slowly ad make sure we stick to its friendly side!

The good old days

Back in the day, when designers worked in command line environments like DOS, we would develop, compile and program our code using *multiple* programs, typing out each command by hand. This was slow and often error prone.

Nowadays, our programs are usually written using some kind of text editor (for example, notepad, textpad, or Word). We call this our 'source code'. This code is a list of instructions that our PIC is going to perform for us – we tell our PIC what we want it to do and when we want to do it. Code can be written in a wide variety of programming languages, but we'll be sticking with two that our PICs can easily understand, 'C' and 'assembler'. C reads almost like English, for example:

```
while this value is true, then
do all these things
```

I will go into more detail when we start coding (writing code) next month, but for now, just remember C is reasonably human friendly. However, assembler is closer to its machine code equivalent, where it loads data from one register, moves it to another register, manipulates it, and then moves it back again. Unlike C, it is often difficult to read, so when we use assembly we will break it down into manageable chunks to make it more understandable.

After we have written our code, it is 'compiled' using another program called a 'compiler'. We briefly mentioned compilers last month, so I'll keep this short. A compiler transforms source code into a computer language, which is written in binary as a series of ones and zeroes. For compactness, this binary information is usually stored in ASCII text format in what's called a HEX file. There are plenty of compilers available for all sorts of applications, some are free, which is great for us hobbyists, while others can be quite expensive and are aimed at the professionals.

This HEX file, now needs to be transferred or copied to our microcontroller. We usually use another program and a physical programmer device to copy this file over to our PIC. If we have issues with the behaviour of our code – let's say it doesn't work – we would debug (correct/amend) our code using a 'software debugger', which is yet another program we need to come to terms with. Now, mastering all these different programs is not impossible, but when things go wrong (which they tend to do… a lot) or you want to change some subtle behaviour, it gets tricky to follow all the changes we need to make through all the programs – things can get complicated very quickly. So, is there a better way?

Integrated development environments

So far, we have explained that you need a text editor for source code, a compiler to compile code into a HEX file, some programming software to program our PIC and a debugger tool in order to find and fix problems. That's a lot of separate programs to learn and get used to.

This is how the idea of an IDE arose. IDEs combine these disparate items into one seamless software tool to create an *integrated* development environment. They incorporate a text editor, compiler, programming tool, debugger and many other tools all into one program. This brings everything we want to access into one easy-to-use visual tool. Instead of typing long commands, we just need one click of a button and we've compiled, checked, programmed and verified, and our PIC is running our latest code…. or to be honest, created a list of how things have gone wrong! But, and it's a *very* big but, our IDE will be very helpful in explaining what has gone wrong and how to put things right. Writing code is not necessarily difficult, but it is error prone, and anything that can help us spot mistakes, is worth its weight in gold.

MPLAB X is our IDE of choice for the PICs, the fact that it is free doesn't hurt either. MPLAB X follows on from MPLAB 8. It was a little rough around the edges when it launched, but five years on it has really proven itself to be a powerful tool. Microchip has recently brought out MPLAB Xpress, which is their cloud-based version of MPLAB X – you don't even have to download it since it can be accessed through your Internet browser. MPLAB Xpress was designed to behave, look and feel exactly like MPLAB X, so there's not much of a learning curve. I'll cover MPLAB Xpress in the future.

Alternative IDEs

There are several other IDEs that we could use to program our PIC. mikroElectronika's C for PIC/dsPIC/PIC32 is very popular. Eclipse and Microsoft's Visual Studio are other development tools. Although they don't natively support the PIC microcontrollers, they can be modified to support them. Note that Eclipse and MPLAB X/Xpress are the only *free* IDEs available for the PIC.

Installation

To start off, let's download and install MPLAB X. While we're at it, we may as well download our compiler and some PIC lessons in a PDF document:

1. Download PICkit 3 Starter Kit User's Guide (**http://tinyurl.com/jyqfeuk**)
2. Download MPLAB X IDE (**http://tinyurl.com/hmehqja**)
3. Download XC8 Compiler (**http://tinyurl.com/h5g9k5l**)

The XC8 compiler is 82MB, but MPLAB X is a bit larger at 550MB, so if your broadband is not the best then leave it running and go for a cup of tea. MPLAB X and the XC8 compiler are both available for Windows, Linux or Mac OS X; the links above let you select for your operating system of choice.

Once the IDE and compiler are installed, we can have a look around and get to grips with this beast of a tool (accept the licence agreement and select default 'Next' options for all questions during install, unless you want to install it somewhere different).

Harmony and Code Configurator

You may be asked to download Harmony and Code Configurator, which are useful for developing larger projects. Feel free to install them if you want to, there's no harm in having a look and tinkering with them once you are happy with MPLAB X.

Harmony (Fig.1) is a firmware development tool designed specifically for 32-bit microcontrollers (PIC32). It allows us to use modular and object-orientated design, Real-Time Operating Systems (RTOS) and other software modules that we would otherwise have to write from scratch. Do note that such systems are way beyond what we will be tackling in this series.

MPLAB®
CODE
CONFIGURATOR

Fig.2. Microchip's MPLAB Code Configurator

Code Configurator (Fig.2) is a powerful development platform that allows us to set our peripherals, drivers and register initialisation all through drop down menus. It then generates seamless, easy-to-understand C code that is inserted into our project. We could start here and ignore this whole series, but I think it's very important to gain an understanding of how to write and debug code for the PICs before using something as powerful as this tool.

Harmony and Code Configurator are both great tools, which I hope to cover at a later time, but for the moment, we'll stick to the basics and really get to grips with MPLAB X.

The IDE user interface

Assuming you've installed MPLAB X and the XC8 compiler mentioned above, we should now be able to open them up.

The first thing you will notice is that there's a lot going on, so let's break it down into smaller more manageable pieces, as shown in Fig.3. We now have five separate blocks: Toolbar, Quick Access Toolbar, Projects Area, Navigator and Code Area.

MPLAB®
HARMONY
Integrated Software Framework

Fig.1. Microchip's MPLAB Harmony for PIC32

1. Toolbar

Starting at the very top and working our way down, we have the toolbar across the top of our screen, (labelled '1' in Fig.3). Here we have the usual suspects – File, Edit, View and Help – they allow us to start new project, open previous project, save, close, print, copy, paste, cut, find and replace.

At this stage we're only interested in the Run and Debug commands, where we can compile, program, execute and stop our code – more on this later.

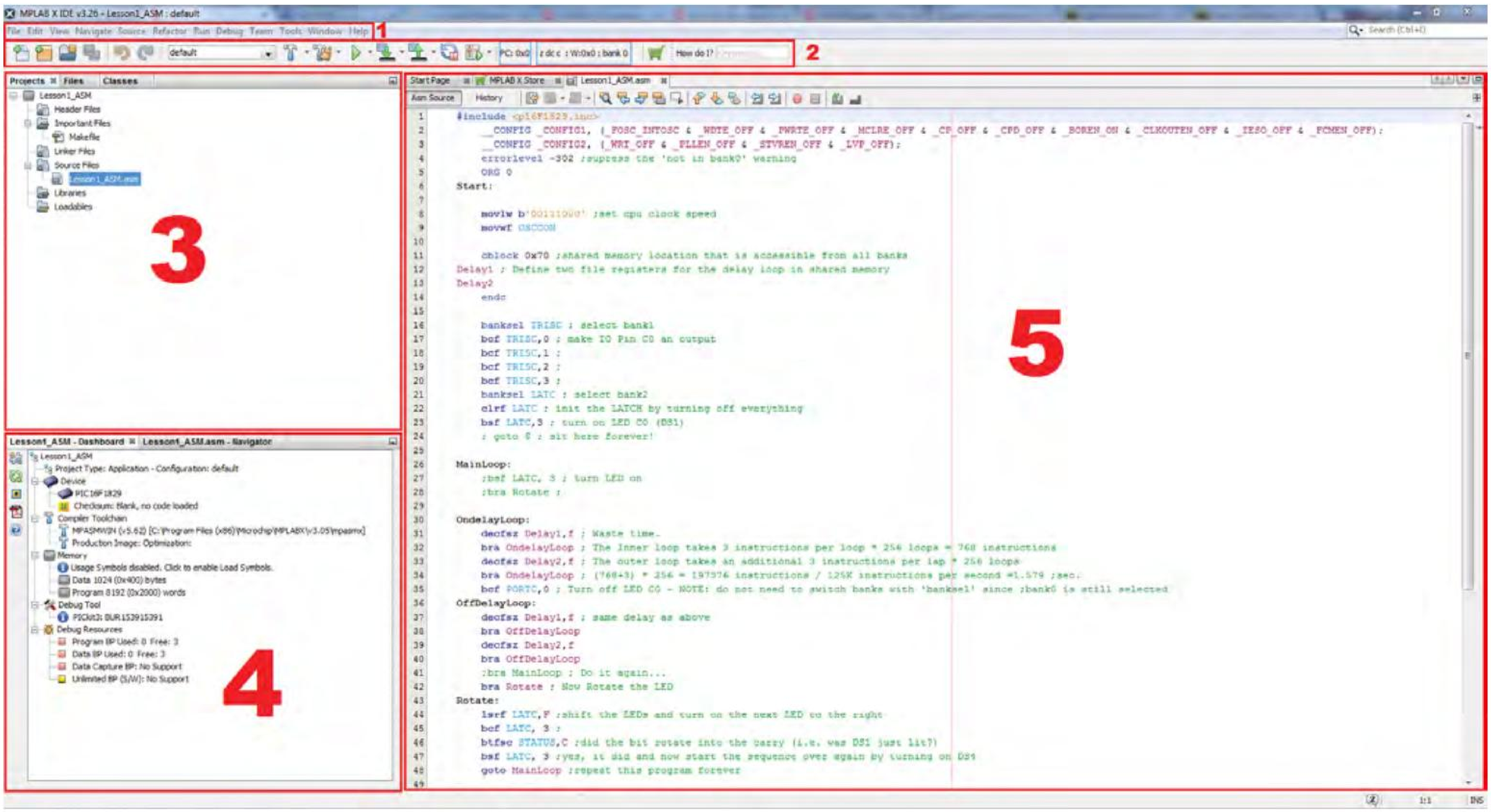
2. Quick Access Toolbar

This toolbar allows us quick access to frequently used functions within MPLAB X (labelled '2' in Fig.3. Here we can open files, create new files, save, undo, redo, compile, run, program and debug. If you hover your mouse over each icon, it will tell you what they do. Some icons have a little black arrow beside them, indicating a drop down menu with more options.

Here, we can also see the Program Counter, Status Flags, a link to the MPLAB X online store and a search bar to query the program on how to perform various actions. This search bar redirects you to Microchip's online Developer Help site.

3. Projects Area

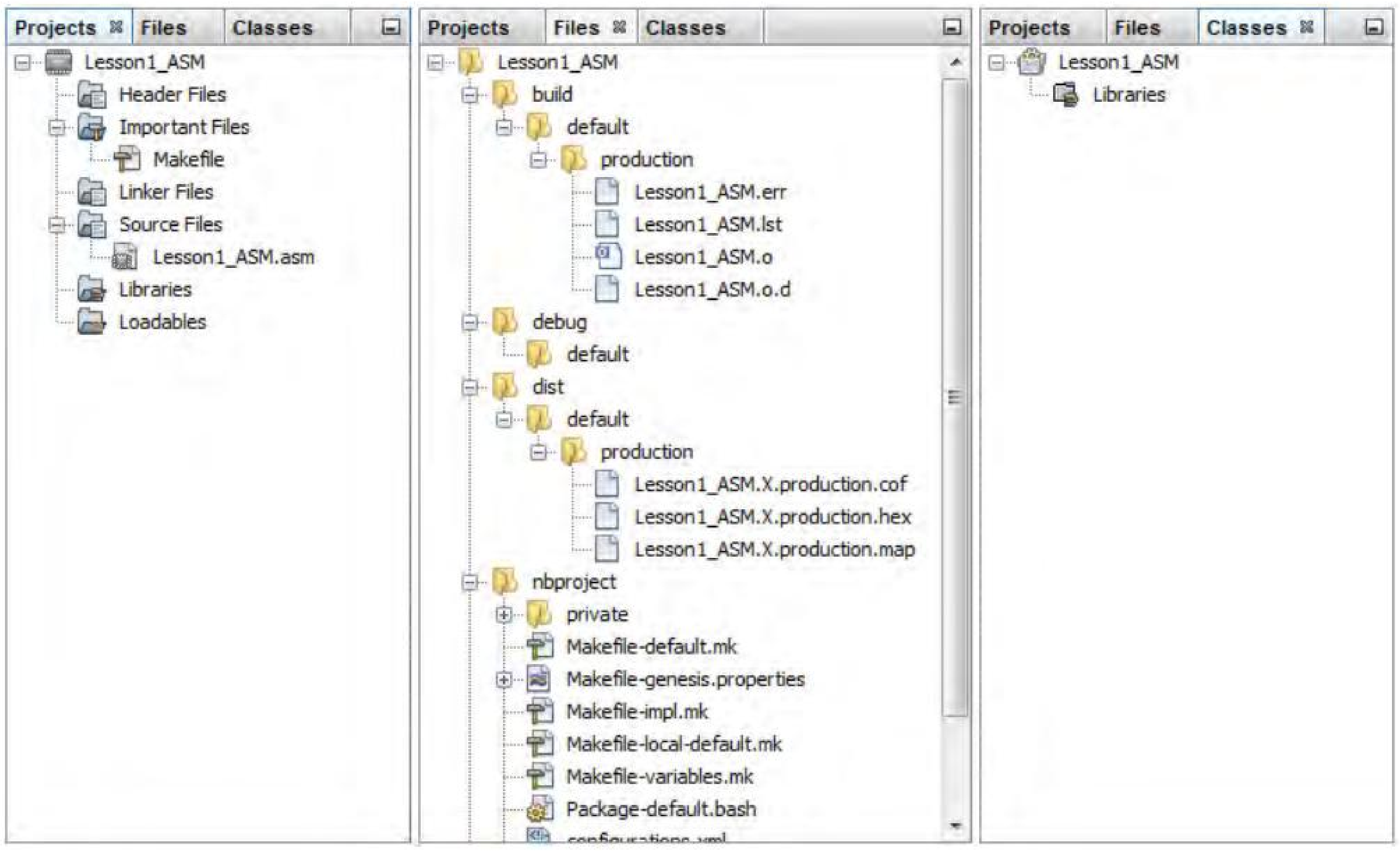
The projects area (labelled as '3' in Fig.3) shows us the project files, broken up into header files, important files, linker files, source files, libraries and loadables. We'll have a closer look at these when we begin to code. We could place any of our files in any one of these areas, but following a logical file structure method helps us



Lesson1_ASM
Project Type: Application - Configuration: default
Device
PIC16F1829
Checksum: Blank, no code loaded
Compiler Toolchain
MPASMWIN (v5.62) [C:\Program Files (x86)\Microchip\MPLABX\v3.05\mpasmx]
Production Image: Optimization:
Memory
Usage Symbols disabled. Click to enable Load Symbols.
Data 1024 (0x400) bytes
Program 8192 (0x2000) words
Debug Tool
PICkit3: BUR153915391
Debug Resources
Program BP Used: 0 Free: 3
Data BP Used: 0 Free: 3
Data Capture BP: No Support
Unlimited BP (S/W): No Support

```
#include <p16F1829.inc>
    __CONFIG _CONFIG1, (_FOSC_INTOSC & _WDTE_OFF & _PWRTE_OFF & _MCLRE_OFF & _CP_OFF & _CPD_OFF & _BOREN_ON & _CLKOUTEN_OFF & _IESO_OFF & _FCMEN_OFF);
    __CONFIG _CONFIG2, (_WRT_OFF & _PLLEN_OFF & _STVREN_OFF & _LVP_OFF);
    errorlevel -302 ;supress the 'not in bank0' warning
    ORG 0
Start:

    movlw b'00111000' ;set cpu clock speed
    movwf OSCCON

    cblock 0x70 ;shared memory location that is accessible from all banks
Delay1 ; Define two file registers for the delay loop in shared memory
Delay2
    endc

    banksel TRISC ; select bank1
    bcf TRISC,0 ; make IO Pin C0 an output
    bcf TRISC,1 ;
    bcf TRISC,2 ;
    bcf TRISC,3 ;
    banksel LATC ; select bank2
    clrf LATC ; init the LATCH by turning off everything
    bsf LATC,3 ; turn on LED C0 (DS1)
    ; goto $ ; sit here forever!

MainLoop:
    ;bsf LATC, 3 ; turn LED on
    ;bra Rotate ;

OndelayLoop:
    decfsz Delay1,f ; Waste time.
    bra OndelayLoop ; The Inner loop takes 3 instructions per loop * 256 loops = 768 instructions
    decfsz Delay2,f ; The outer loop takes an additional 3 instructions per lap * 256 loops
    bra OndelayLoop ; (768+3) * 256 = 197376 instructions / 125K instructions per second =1.579 ;sec.
    bcf PORTC,0 ; Turn off LED C0 - NOTE: do not need to switch banks with 'banksel' since ;bank0 is still selected
OffDelayLoop:
    decfsz Delay1,f ; same delay as above
    bra OffDelayLoop
    decfsz Delay2,f
    bra OffDelayLoop
    ;bra MainLoop ; Do it again...
    bra Rotate ; Now Rotate the LED
Rotate:
    lsrf LATC,F ;shift the LEDs and turn on the next LED to the right
    bcf LATC, 3 ;
    btfsc STATUS,C ;did the bit rotate into the carry (i.e. was DS1 just lit?)
    bsf LATC, 3 ;yes, it did and now start the sequence over again by turning on DS4
    goto MainLoop ;repeat this program forever
```

Fig.3. MPLAB X IDE window, Toolbars, Quick Access Toolbars, Projects Area, Navigator and Code Area


Projects
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Classes
Lesson1_ASM
Header Files
Important Files
Makefile
Linker Files
Source Files
Lesson1_ASM.asm
Libraries
Loadables
build
default
production
Lesson1_ASM.err
Lesson1_ASM.lst
Lesson1_ASM.o
Lesson1_ASM.o.d
debug
default
dist
default
production
Lesson1_ASM.X.production.cof
Lesson1_ASM.X.production.hex
Lesson1_ASM.X.production.map
nbproject
private
Makefile-default.mk
Makefile-genesis.properties
Makefile-impl.mk
Makefile-local-default.mk
Makefile-variables.mk
Package-default.bash
Libraries

Fig.4. MPLAB X IDE Projects Area tabs, Projects, Files and Classes

manage our code and libraries in an easy-to-use way.

Fig.4 shows the alternate tabs for this area: Projects, Files and Classes. The Files tab shows our files as they are laid out in our project directories. This can be very useful when trying to find out exactly where a file is stored. The Classes tab shows the project classes being used in our project. This can be handy to have for breaking down a project into easy-to-manage classes. Again, we'll cover this more when we begin to code.

4. Navigator

In our Navigator window (labelled '4' in Fig.3) there are two tabs: Dashboard and Navigator. Dashboard shows the PIC we've chosen, what compiler toolchain we're using (in this case MPASMWIN for assembler language projects), the Data and Program memory available to us in our chosen PIC (and how much we're using), and our selected debugging and programming tool (labelled as 'PICkit3' here).

Our Debug Resources are also listed here. These are 'breakpoints', which are like hooks in our code that tell our PIC to stop when they try to run this code. This allows us to see into the behaviour of our code, we can examine the value of registers and variables in order to verify that they are what we expect. The PICkit3 has somewhat limited abilities here compared to more expensive programmers like the ICD3 (see last month), which has much more complex hardware and software breakpoints. However, the ICD3's bells and whistles come at a price, so we will stick to the reasonably priced and still very powerful PICkit3.

5. Code Area

The Code Area (labelled as '5' in Fig.3) is our main coding area. This is basically a text editor, with a few enhancements. As you can see, in this area the text can have different colours, representing different parts of the code. Colour coding is a great way to visually categorise each part of your code and makes it much easier to read. These can be changed in Tools-> Options-> Fonts & Colours, but I recommend leaving the colour codes in their default settings. The colour defaults in the Code Area are as follows:

Green – 'comments', which are ignored by the compiler. Comments are a great way to make notes throughout our code to remind us what we want to achieve and what the code we are writing actually does.
Purple – 'identifiers'
Dark blue – 'instructions' and 'directives'
Light blue – registers, which are microcontroller-dependent code pieces specific to our PIC.
Red – errors
Orange – for strings and characters
Yellow – for warnings

'Must haves' for upcoming articles

I'll be walking you through the setup, building and programming of our very own PIC projects, and I recommend you get your hands on the following software and hardware, so you can follow me as I introduce ideas and techniques:

1. Purchase the PICkit 3 Low Pin Count Demo Board (**http://tinyurl.com/h2jj2ek**)
2. Purchase the PICkit 3 Programmer + USB Cable (**http://tinyurl.com/zcpx3le**)
3. PC with an Internet connection to download the IDE, compiler and user guide.

Next month

We've done two months of theory, which has perhaps been a little dry, but it'll be worth it – I want to ensure we have strong foundations to build upon. We've installed MPLAB X and had a look at where everything lives. Next month, we're going to get our hands dirty with the PICkit3 Low Pin Demo Board and the PICkit3 Programmer, so make sure you have these vital items and can follow along and become a PIC king (or queen).

Not all of Mike's technology tinkering and discussion makes it to print.

You can follow the rest of it on Twitter at @*MikePOKeeffe*, up on *EPE Chat Zone* as *mikepokeeffe* and from his blog at *mikepokeeffe.blogspot.com*

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Practically Speaking

Robert Penfold looks at the Techniques of Actually Doing it!

Starting on the cheap

AS MOST readers will have discovered for themselves, when using search engines, you do not always get what you expect. Some results are *risqué* or downright indecent, while others are nice tries but completely wrong. When searching an auction site for an old BC348 communications receiver of World War Two vintage, I was mainly offered BC348 transistors. To be fair, in this case the search engine was accurate, and was not producing numerous erroneous results by trying too hard to be helpful. Exercising a little patience proved fruitful, and the required item did eventually turn up.

Cheap as silicon chips

When searching for a headphone amplifier the results were more apt, but I could not help noticing that a super-fi kit of parts was remarkably cheap compared to the ready-made alternatives. The kit included the circuit board and all the components needed to complete the board. Things like a case, mains transformer, and control knobs had to be obtained elsewhere. Even so, for a tenner (or about $14.60) it was still remarkably cheap. When searching for the elusive BC348 I noticed that there were various radio-related kits with 'peanuts' asking prices.

A little investigation revealed that there were actually a number of inexpensive electronic kits advertised on the eBay site, some starting at just 99 pence including delivery! I ordered one of these out of idle curiosity, and it did eventually turn up (Fig.1). It lacked the sockets for the two integrated circuits that were pictured in the listing, and gained an extra LED, but at a fully inclusive price of 99p I did not have the nerve to complain. The completed item (Fig.2) did work, producing an electronic version of a miniature roulette wheel.

These cheap kits mostly originate from China, and delivery can take a few weeks. In the past I have often recommended that beginners should buy some stripboard and a few cheap components such as resistors so that they can practice soldering before starting their first project. However, at this sort of price it might be better to buy some cheap kits to practice soldering, even if you have no interest in the finished item. It should be worth the wait.

If cheap kits are bought purely for practice, it is just a matter of choosing the ones that provide the most components for the least money. The kits vary from just the printed circuit board (PCB) to complete kits that have almost everything you need, including the case and connecting wire. Of course, you still have to supply your own solder and batteries, plus a soldering iron and any other tools required for assembly. Clearly it is necessary to read listings carefully to ensure that you know exactly what you are ordering. Provided no exotic components are involved, a kit that contains just a circuit board and all the parts needed to complete it, should offer the best value in the current context.

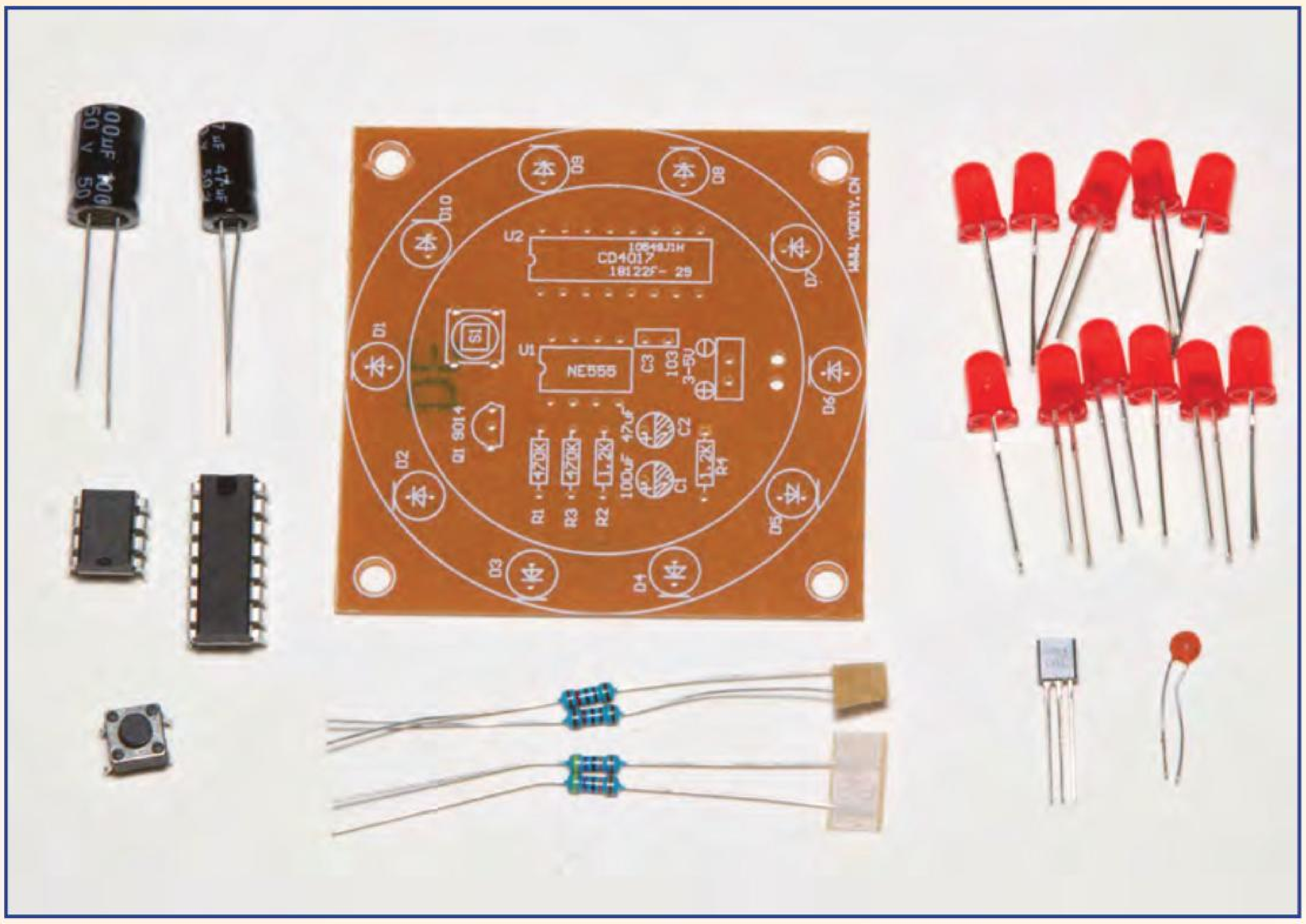


Fig.1. A (more or less) complete set of parts for 99p. The PCB is in the middle, and clockwise from the top right: 11 LEDs, a disc ceramic capacitor, a transistor, four resistors, a pushbutton switch, two ICs, and two electrolytic capacitors

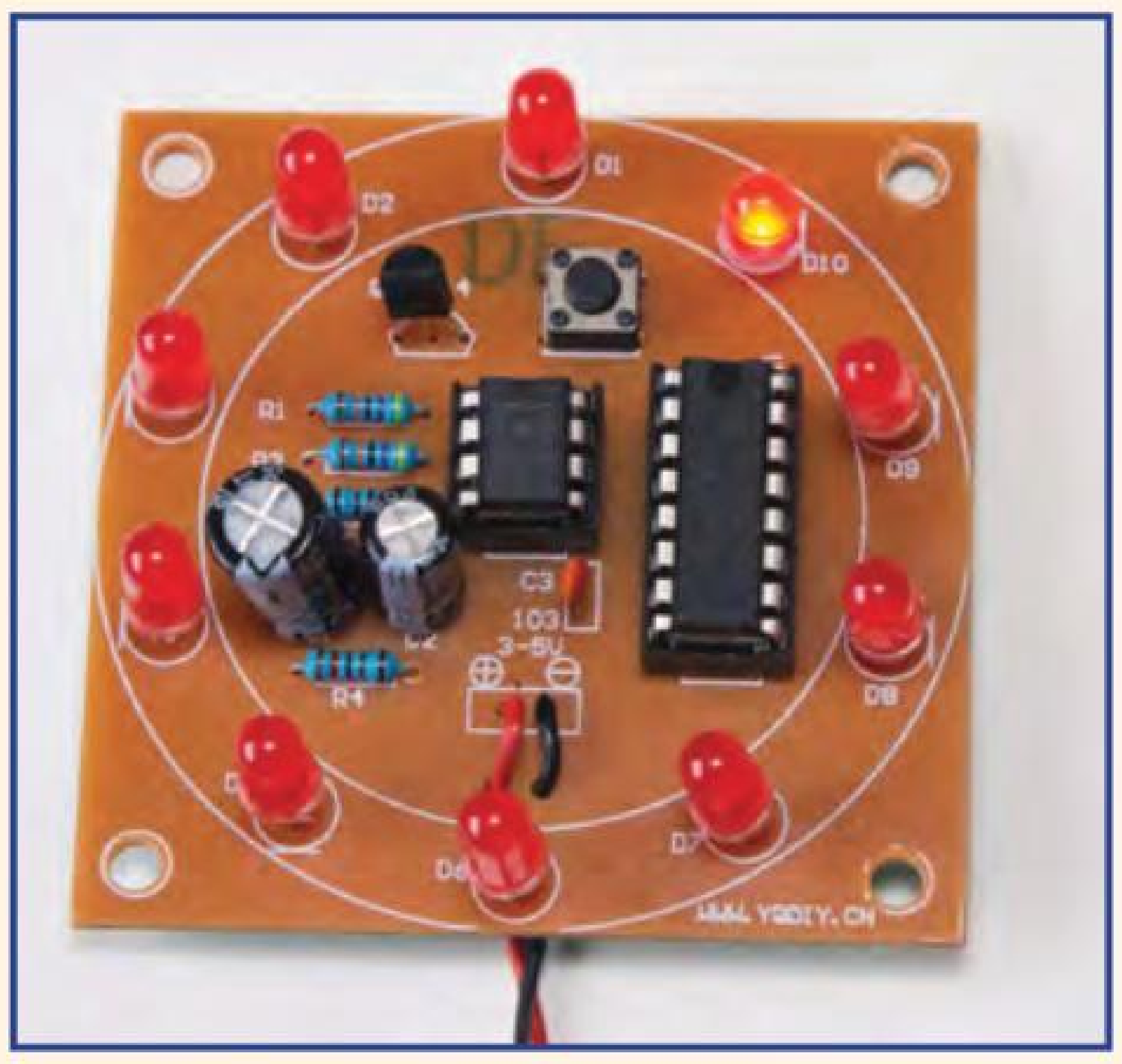


Fig.2. The completed LED roulette wheel. The LED display 'spins' fast at first, gradually slows down, and stops with the winning LED switched on

Chinese puzzles

I think it makes sense to make serious attempts to successfully complete a kit, even if it is just purchased to help perfect your soldering technique, and you have no real interest in the finished item. That way you are also practising other important skills, such as correctly identifying components and, where appropriate, getting them connected the right way around. However, it is only fair to point out that there are likely to be problems in addition to the normal type encountered when making a start at electronic project construction. Many of the kits seem to be designed for home consumption in China rather than for export to English-speaking countries. Component type numbers and values are in normal western form, but just about everything else is in Chinese, which is based on symbols rather than an alphabet.

Normally, there is no problem in deciding which component fits into each position on the circuit board, but there can be occasional problems. As an example, I tried building a medium wave superheterodyne (superhet) radio kit, which was a bit 1960/70s in design, and had two intermediate frequency transformers and an oscillator coil. These looked identical apart from the colours of the adjustable cores, which made it easy to determine which was which. Fortunately, the Chinese symbols for the three colours were marked on the board itself, and on the circuit diagram. The solution was to use a free online translation service to provide the symbols for 'red', 'black' and 'white', and to then match these to the symbols on the documentation.

Some of these kits seem to have an educational element, which may seem to be of no great importance. However, in the case of the superhet radio there were deliberate breaks in the copper strips that could be used as monitoring points for checking current flows. These breaks have to be soldered over to get the radio to work. Such things may be clearly explained in the instruction sheet… but might be a bit puzzling unless you can read Chinese!

Well adjusted

With some gadgets you simply build them, connect a power source, and then use them, but with others it is necessary to make one or more adjustments before they will function properly. The superhet radio did provide one or two stations when it was first switched on, but it required numerous adjustments in order to get it reasonably well aligned and functioning properly. If there were any alignment instructions in the brief documentation, they were in Chinese, and a free translation service would probably be inadequate with something as technical as this. It is a matter of finding out from elsewhere or working it out yourself.

In the UK, with cheap kits bought from abroad there should be no problems with taxes, import duties, or other additional expenses, because the threshold for this type of thing is £18.00. Bear in mind that it might be illegal to use any device that includes a radio transmitter unless you have the relevant license. Radio regulations seem to vary from one country to another, so a transmitter bought from abroad might not be licensable in your country.

Identity crisis

Whether you obtain a cheap kit, an expensive kit, or amass the parts yourself, the first task before starting to build anything is to identify each of the components, and determine where they fit on the circuit board.

Resistors

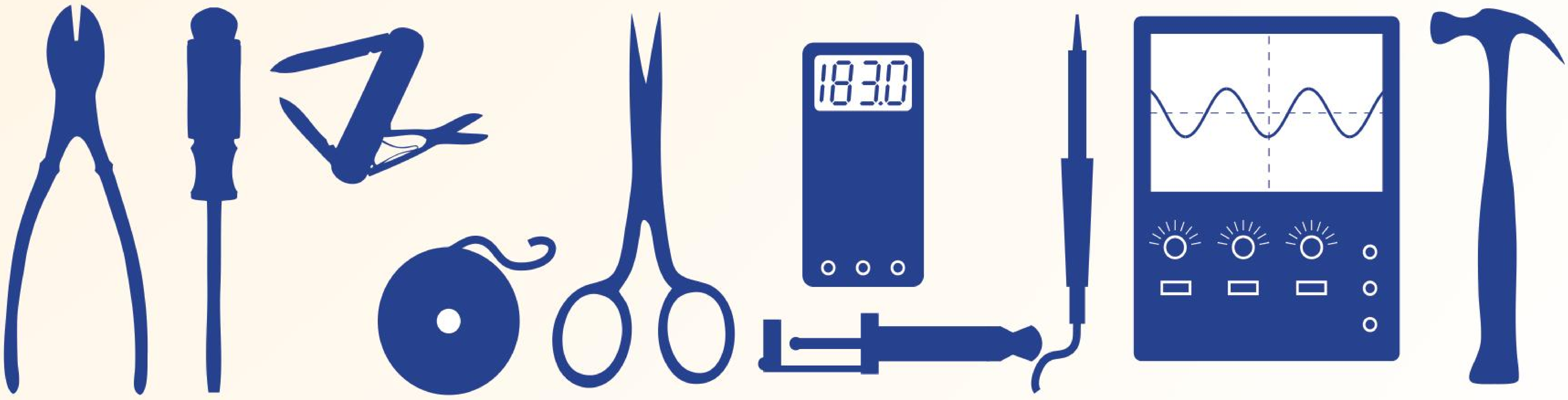
These have two leads and are small cylindrical components. They usually have the value marked using four or five coloured bands. I will not cover resistor colour codes again here, but if in doubt, there are plenty of websites that will convert any colour code into the corresponding resistance value.

Capacitors

These come in a wide range of shapes and sizes. These days they are mostly box or disc shaped and have two leads. The value is usually written on them and colour codes are no longer used to a significant degree with capacitors. Low-value disc capacitors have their value in picofarads, marked using one or two digits. Higher values have a third digit, which indicates the number of zeros to be added to the first two digits. For example, '103' means that the value is '10' plus three zeros, in other words 10000 picofarads. For high values, divide the value in picofarads by 1000 to obtain the value in nanofarads. In this example, the capacitor is a 10 nanofarad type. With the Chinese kits you may find that this method is also used on the circuit board and the circuit diagram, which makes it easy to match everything together properly. Capacitor markings in general can be a bit confusing, but again, there are websites that can help.

Electrolytic capacitors

These are cylindrical components, and in modern electronics they are almost invariably of the vertical-mounting printed circuit variety. They are used to provide high values, where normal capacitors would be impractical because they would be physically too large. Unlike resistors and normal capacitors, the electrolytic variety are polarised components that must be connected the right way round. They are sometimes marked with '+' and (or) '–' signs to indicate their polarity, but the modern trend is for the negative terminal to be indicated by a large bar



marked down the appropriate side of the body. Presumably this is meant to be an outsize minus sign! On the circuit board or the component layout diagram there will either be plus and minus signs, or something to represent the bar next to the negative terminal.

Transistors

With a very few exceptions, transistors have three leads called the base (b), emitter (e) and collector (c). In most cases there is no need to get involved with diagrams identifying the leads of the particular transistors in use. The component layout diagram or the overlay on the circuit board itself usually indicates the correct orientation of a transistor using a simple physical representation. If you do need to consult a transistor connection diagram, remember that the convention is for these to be base views. In other words, they show the device as viewed with the leads pointing towards the viewer.

Diodes and rectifiers

A rectifier is essentially the same as a diode, and the only differences are that a rectifier is generally the larger of the two, and it can handle higher currents. This type of component is a sort of electronic valve that only permits a current flow in one direction. This means that rectifiers and diodes must be connected the right way round, or they will allow current flow in the wrong direction and block it in the correct direction. Particularly with rectifiers, this could have dire consequences for some of the other components in the circuit. The polarity of diodes and rectifiers is usually indicated with a band marked around the body near the cathode terminal. On printed circuit overlays and layout diagrams there will usually be a physical representation of the component, complete with the cathode band, or the diode circuit symbol. The latter has a bar at the cathode end, so it is just a matter of matching the bar on the symbol with the band on the body of the actual component.

Integrated circuits (ICs)

The integrated circuits used in electronic projects are mostly of the DIL (dual in-line) variety. These have a 'U' shaped indentation at the pin 1 end of the component, and/or a round dimple next to pin 1; there should also be a corresponding marking on the printed circuit overlay or component layout diagram. If you look at the copper pads on the underside of a printed circuit board, you will usually find that one pad of an IC cluster is rectangular, whereas the others have a rounded shape (Fig.3). The rectangular pad is for pin 1 of the integrated circuit. When looking at the underside of an integrated circuit, the pin numbering goes in a clockwise direction. If you need to refer to a pin function diagram for an IC, it is important to realise that the convention is for these to be top views. In other words, they show the device with the pins pointing away from the viewer. This is the opposite to the convention for transistors, where base views are the norm. Even if an integrated circuit has a transistor style case and leads, unless stated otherwise, pin function diagrams will still be top views.

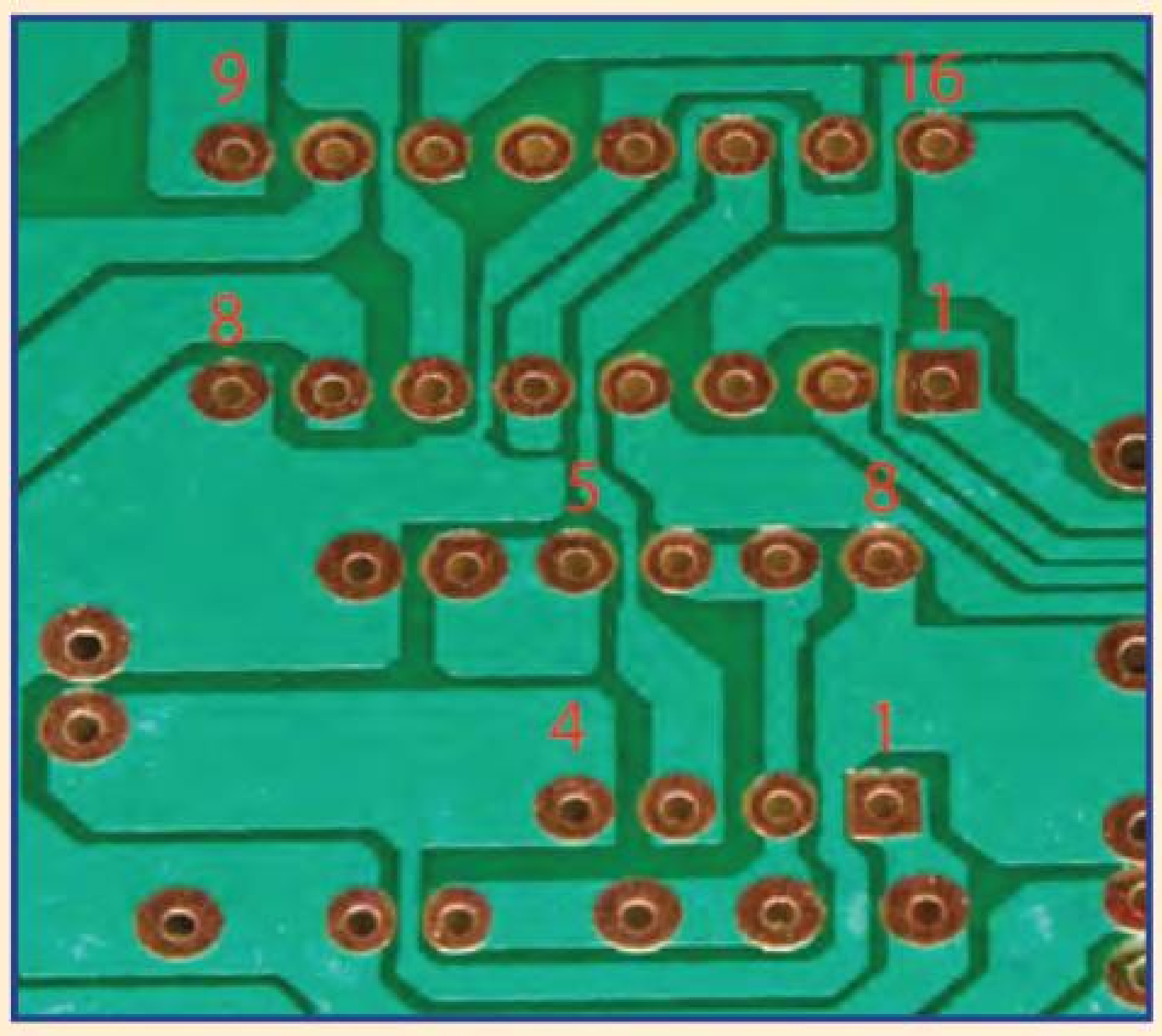


Fig.3. A square pad on the PCB is normally used to identify pin 1 of an IC. When viewed from this side, the pin numbering runs in sequence in a clockwise direction

LEDs

Light-emitting diodes, like other diodes, only permit a significant current flow if they are fed with a voltage of the correct polarity. Accordingly, if fitted with the wrong polarity they will not work. The cathode lead is normally shorter than the anode one, and the body of the component is flat rather than round next to the cathode lead. Unfortunately, not all LEDs conform to these conventions, but most do. Component overlays and layout diagrams should have either the diode circuit symbol or a physical representation, complete with the 'flat' next to the cathode lead, to indicate the correct method of connection.

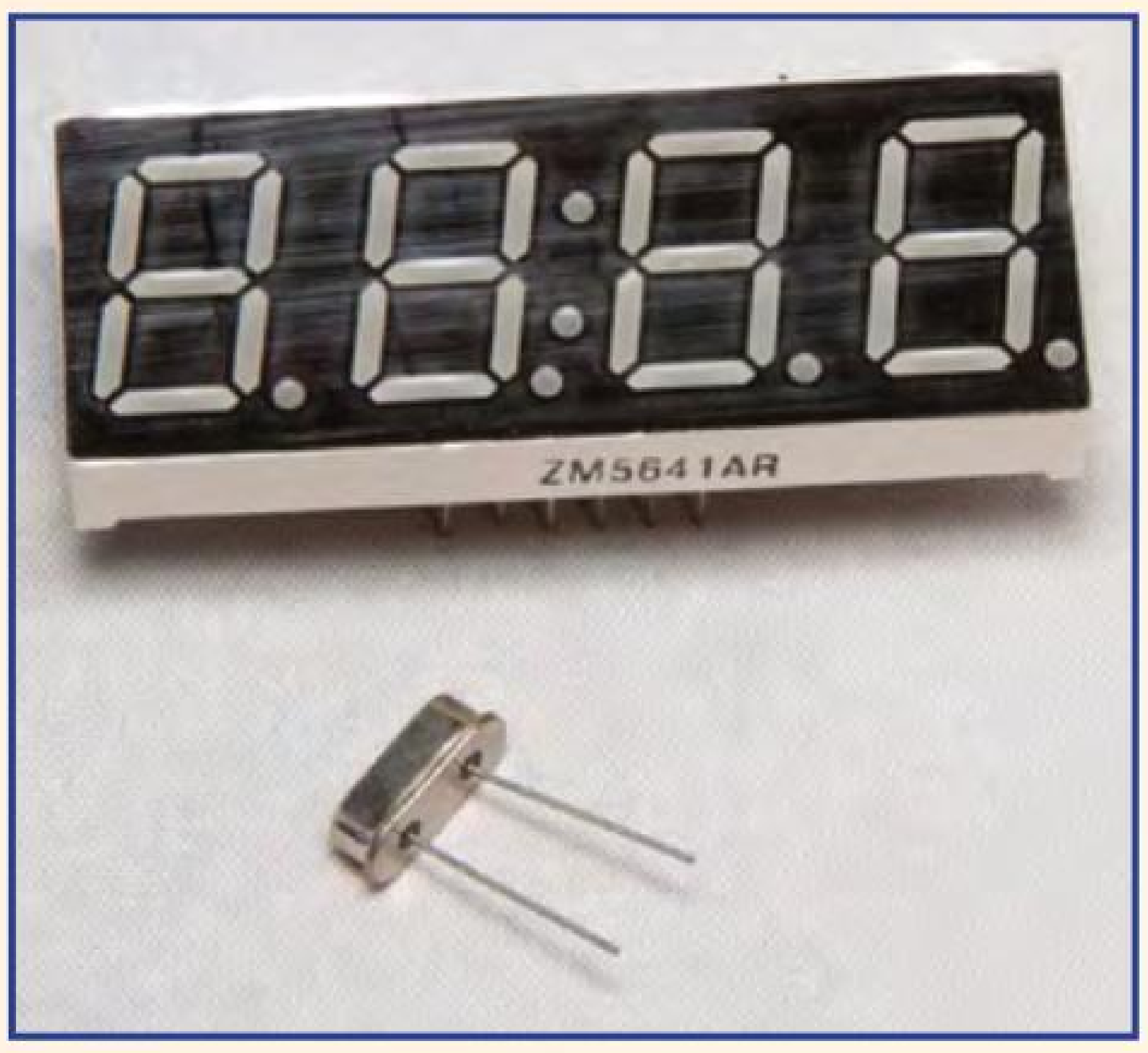


Fig.4. A multiplexed 7-segment LED display having four sections, with decimal points to show which way up it is fitted! Below this is a 12MHz crystal

It would be easy to design 7-segment LED displays (Fig.4 top) so that they can only be fitted the right way around, but with most it is possible to fit them upside-down. It is difficult to remove and reinstall this type of multi-pin component if a mistake is made, so do make sure that the decimal point or points are where they should be, at the bottom of the display, before you start soldering one into place.

Crystals

Crystals (Fig.4 bottom) are often used in digital clocks, timers, and digital circuits in general. Modern types have leads rather than pins, and are soldered direct to printed circuit boards with no holders being used. They need to be soldered into place fairly quickly since heat flowing up the leads to the crystal could impair its accuracy. Crystals can be connected either way around.

Switches

Switches vary greatly in appearance, and range from simple push-button types to multi-way rotary types. If a switch can be fitted onto a circuit board with more than one orientation, it does not usually matter which one is used.

Potentiometers

Potentiometers (Fig.5 left), which are also known as variable resistors, are used for things like volume and tone controls. With modern projects they are often of the printed circuit mounting type, and are fitted on the circuit board. While it might be possible to fit one with the wrong orientation, fairly obviously the control shaft should stick out from the circuit board and not over it. Preset potentiometers are much smaller than the normal variety, and they are adjusted using a small screwdriver. Normally, these can only be fitted on the circuit board with the correct orientation.

Relays

A relay (Fig.5 right) is a mechanical switch operated by an electromagnet. Modern types are housed in a plastic case with printed circuit pins on the underside. All the ones I have encountered in recent years can only be fitted onto the board if they have the correct orientation.

Sockets

These days, sockets are often mounted on the circuit board (Fig.5 third from left). This is another example of where it might be possible to fit the component the wrong way around, but the correct orientation is usually self-apparent.

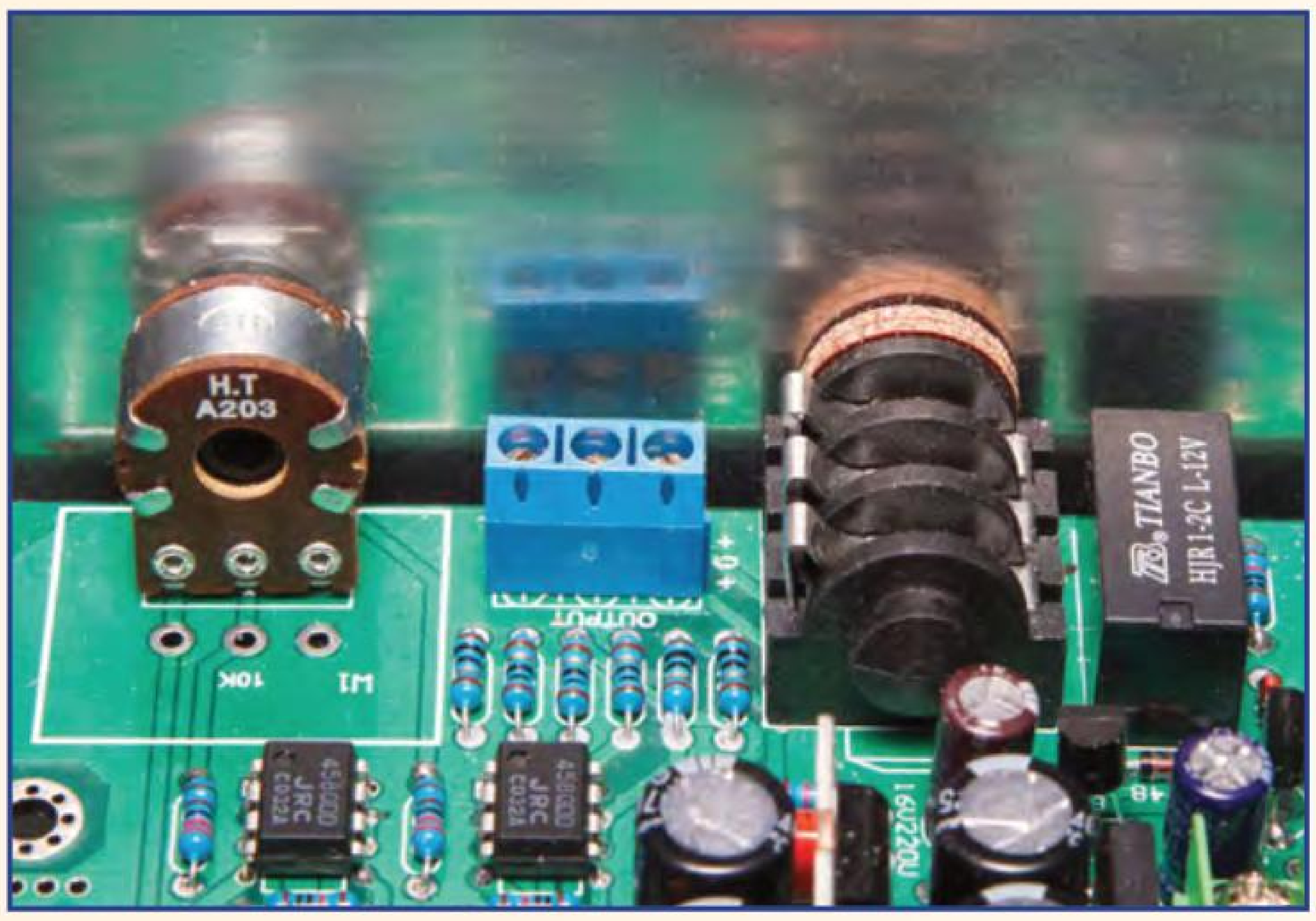


Fig.5. From left to right along the top edge of the board are: a dual gang potentiometer, a connector block for connections to off-board sockets, a standard jack socket, and a relay. The board is designed to accept potentiometers with two different pin arrangements, which is why there are three holes left unused just below the potentiometer

Soldering

This is a complete subject in itself, but a good starting point is Alan Winstanley's *The Basic Electronics Soldering & Desoldering Guide*, which is available on the *EPE* website at: **www.epemag.wimborne.co.uk/solderfaq.htm#irons**

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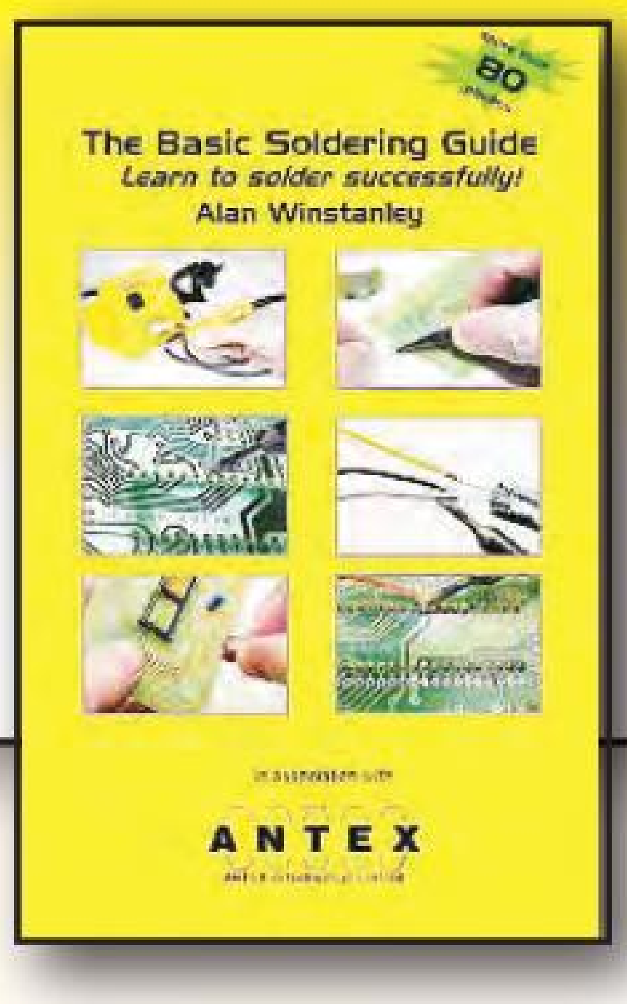

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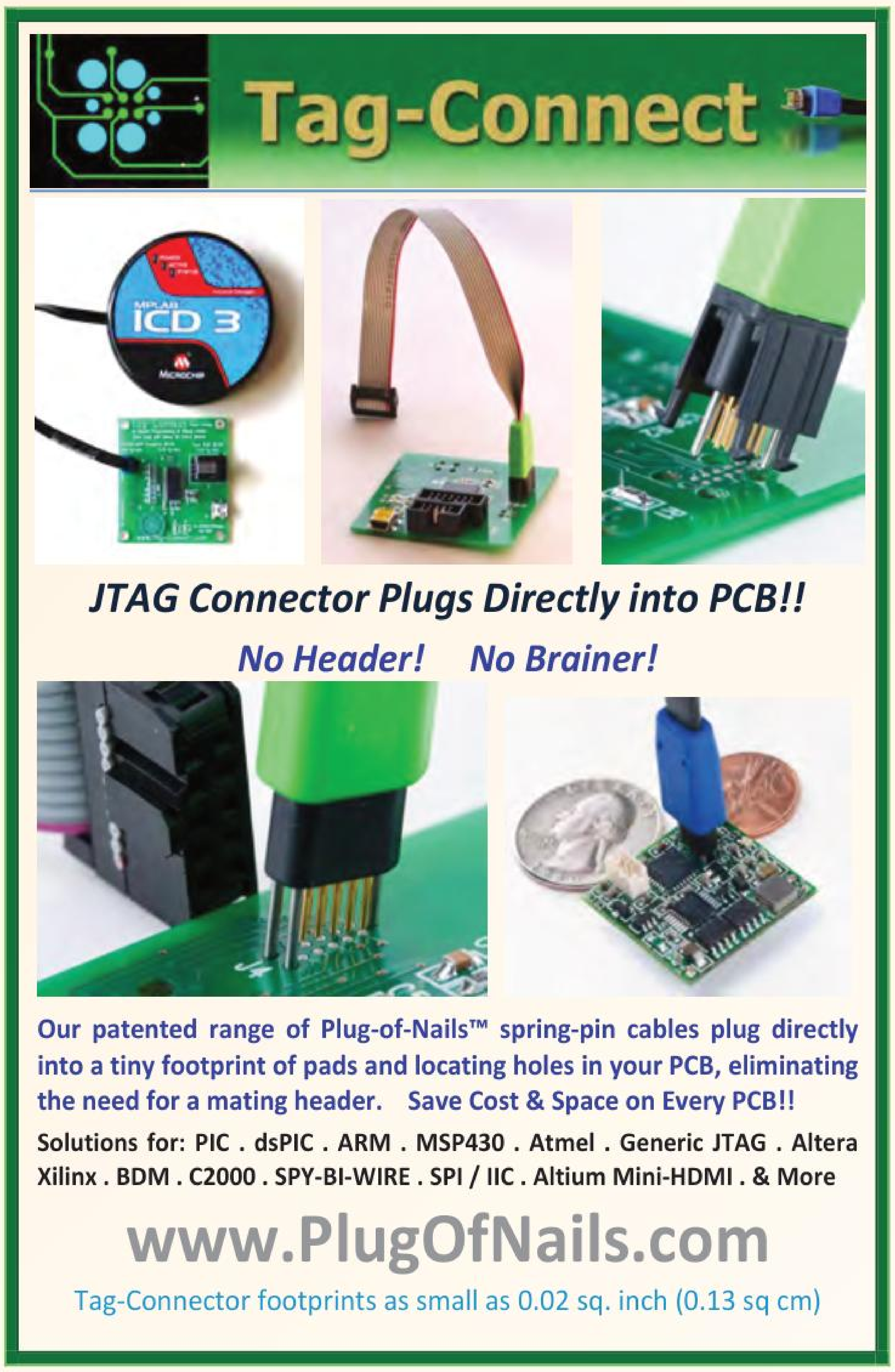

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REGULAR CLINIC

BY IAN BELL

State machines – Part 2

LAST MONTH, in response to an *EPE Chat Zone* post by regular contributor ***atferrari***, we started discussing state machines. ***atferrari*** asked specifically about implementing state machines in microcontroller code – however, as we noted last month, state machines are important in both digital hardware design and software development. An understanding of the basic principles of state machines is very useful for anyone interested in designing electronic circuits and systems.

Key concepts in state machines are the state and the transition. At any given time a state machine has a particular current state. In a digital hardware implementation, the current state is held as a set of 1s and 0s in a set of flip-flops. In a software implementation, the state will usually be a variable in the code. In each state the state machine may perform particular (external) actions, or in circuit terms, have particular logic levels on its outputs.

A state machine will change to a different state (the 'next state') if certain conditions or events (inputs) occur – this is called a 'transition'. In circuit terms the transitions will be defined in terms of the required logic levels on the machine's inputs. In software the conditions will usually be expressed (in the code) in terms of conditional statements (eg, `if` or `switch` statements). In microcontroller code these conditions could directly use logic levels on the chip's inputs, but of course other information available to the code may also be used. As well as performing particular actions associated with each state, state machines may also perform actions related to transitions.

State machines can be defined using state diagrams (see Fig.1), which are very useful in visualising the behaviour of the machine.

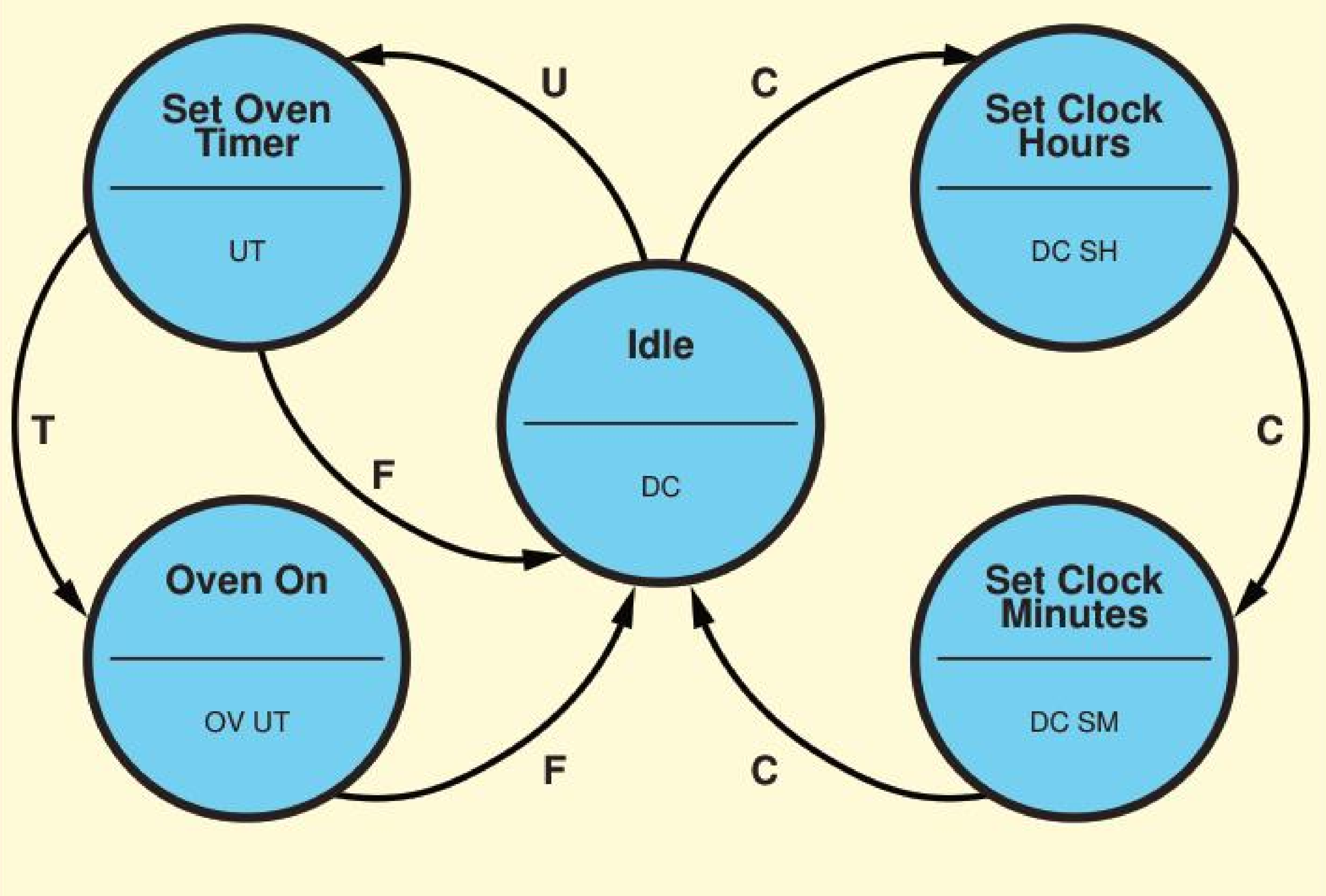
Example recap

Many everyday systems can be described using state machines. Last month, we started to discuss such an example in depth, specifically the (simplified) behaviour of a microwave oven user interface. The purpose of this example was to show how the operation of a system can be defined in terms of a state machine, and the thinking involved in developing the state machine description. This month, we will continue to develop the state machine definition and move on to discuss some aspects of implementation.

The oven in our example has two controls that we are concerned with – a 'Clock-Set' pushbutton, which is employed if the user wishes to set the current time on the clock, and an 'up/down' rotary control used to set the clock and cooking time. There is also a display which shows the time of day, unless the oven is being used, in which case it shows the cooking time.

'Reading' the state machine diagram in Fig.1 we see that the microwave controller is in the Idle state when it is not being used, during which time it displays the time of day. If the user wishes to adjust the clock he can press the clock button once to set the hours (Set Clock Hours state) and press it a second time to set the minutes (Set Clock Minutes state). The control knob adjusts the time values in these states. To return to the current time display the clock button is pressed a third time.

If the user wishes to cook something he can turn the control knob clockwise while in clock display mode (Idle state). This will change the display to show the cooking time, which can be adjusted by turning the control knob in either direction (Set Oven timer state). If the cooking time is wound back down to zero the display returns to showing the clock (The F transition from the Set Oven timer state to the Idle state). Once the required cooking time is set the user stops moving the control for five seconds to initiate cooking (The T transition from the Set Oven timer state to the Oven On state). When the cooking time is up, the oven returns to displaying the clock (return to Idle state). Cooking time can be adjusted as cooking progresses, but if it is reduced to zero then cooking stops (again returning to the Idle state).



Inputs

C	'Clock-Set'	User presses clock button
U	'Up'	User rotates control knob clockwise one step
T	'Timeout'	User has not moved control knob for 5 seconds
F	'Finished'	End of cooking time (oven timer reaches zero)

Outputs

OV	'Oven On'	Power applied to oven, oven timer counts down
UT/DC	'User Timer'	Cooking time value can be changed by moving control knob Display shows (remaining) cooking time
	'Display clock'	Display shows time from clock
SM	'Set Minutes'	Clock minutes value can be changed by moving control knob
SH	'Set Hours'	Clock hours value can be changed by moving control knob

Fig.1. Flawed state machine example from last month

Logic flaws

The state machine described above is not the complete oven system. Our description assumes the existence of additional circuits and/or blocks of software code. For example, there is a real-time clock, a timer, and an interface to the control knob to produce the up and down pulses/instructions as it is turned. Our state machine performs a control, coordination and sequencing role with respect to these other subsystems. It is common for state machines to be used in this way. Often the subsystems being controlled may themselves be state machines.

The state machine may seem to make sense in preceding discussion, but the current version has fundamental logical flaws. For example, there are two transitions out of the Idle state (conditions *U* and *C*) – what happens if they occur at exactly the same time? (By 'at the same time' we really mean close enough in time that it is not perceived as different by the circuitry/software.) Given the speed of logic devices, this may be in the microsecond or nanosecond timescale. The fact that it is very unlikely that a user could do this does not prevent it from being a problem in the state machine definition. What happens if these conditions do actually occur at the same time? What is the next state? In the state machine in Fig.1 there is no answer to this – it is not defined.

Decisions

We have to decide what happens if both conditions occur at once. We could keep the system in the idle state (ignore the unwelcome 'double instruction'), or we could give precedence to either clock-setting or setting the cooking time. We will choose to give clock-setting precedence on the basis that the only reason the Clock-Set button is pressed is for this purpose, but the control knob is used in both functions – maybe the user moved the control a little too soon. This means that the condition for change to the Set Oven Timer state is now 'U AND NOT C' (the control was rotated clockwise and the Clock-Set button was not being pressed), which can be expressed in Boolean logic as: $U\overline{C}$.

We also note that the condition for staying in the Idle state is 'NOT U AND NOT C' (the control is not being rotated clockwise and the Clock-Set button is not being pressed). We write this as $\overline{U}\,\overline{C}$.

This represents a 'self loop' on the state diagram – drawn as a transition starting and ending at the same state.

These conditions are shown on the revised state machine diagram in Fig.2, along with other changes which will we will be discussing.

Boolean

In Boolean algebra expressions the bar above the symbol means logical NOT. Writing two adjacent variables indicates logical AND, in much the same way as writing xy in standard algebra means x multiplied by y. The other key Boolean logical operation – OR (which we have not used here) – is denoted by the '+' symbol, so, for example, '$A + B$' means 'A OR B'.

A similar situation to the one we have just discussed occurs with the two transitions out of the Set Oven Timer state. Again, we choose to give precedence to one of the inputs, in this case the Finish condition (F). Our justification is that this represents a definite action by the user (control knob) which should override the system automation (timeout to start the oven). The Boolean expressions for the new transition are similar:

$\overline{F}T$ Go to Oven On state if Timeout occurs without Finish condition present

$\overline{F}\,\overline{T}$ Stay in Set Oven Timer state if neither timeout nor Finish condition present.

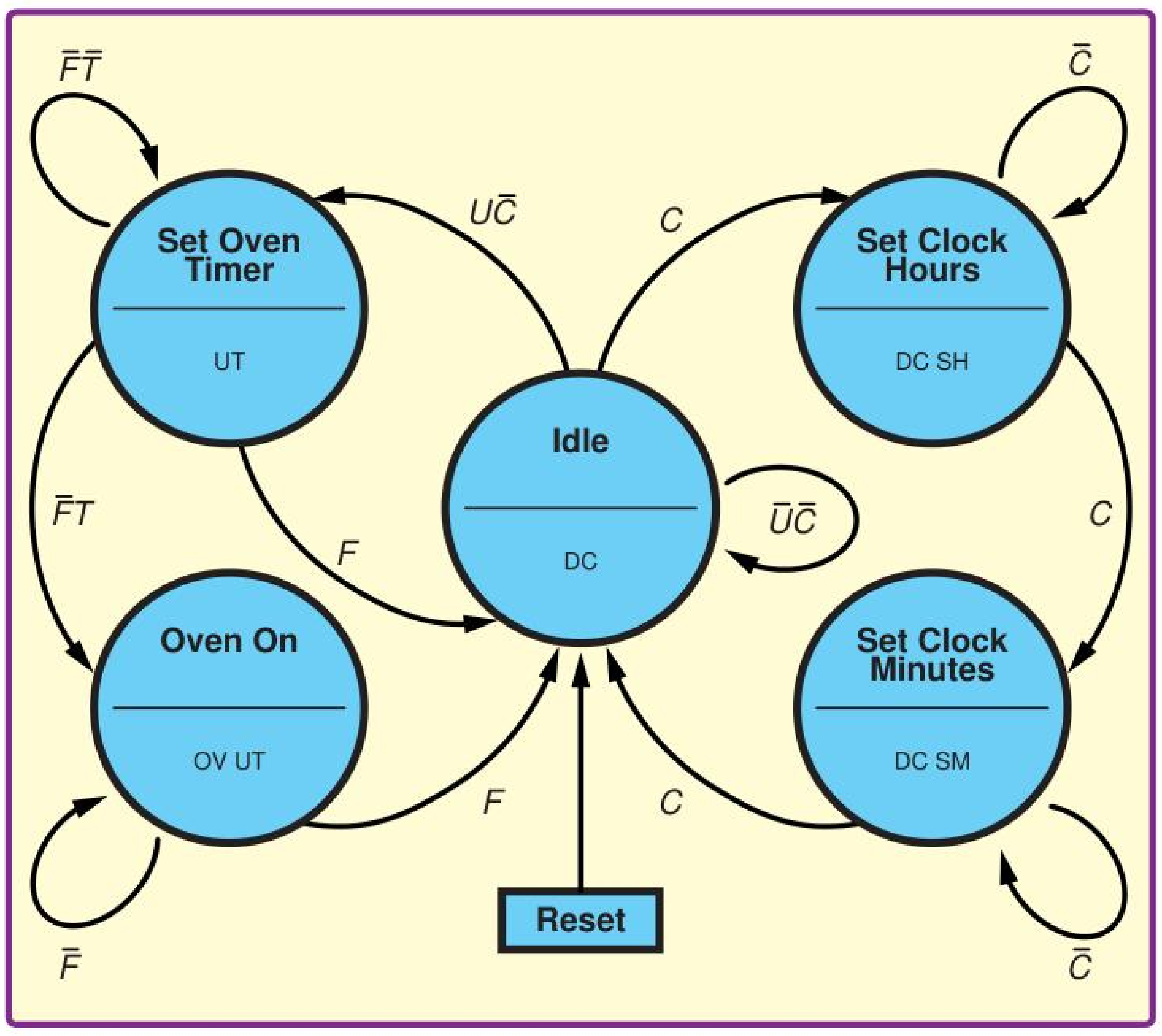


Fig.2. State machine example with better defined transition logic

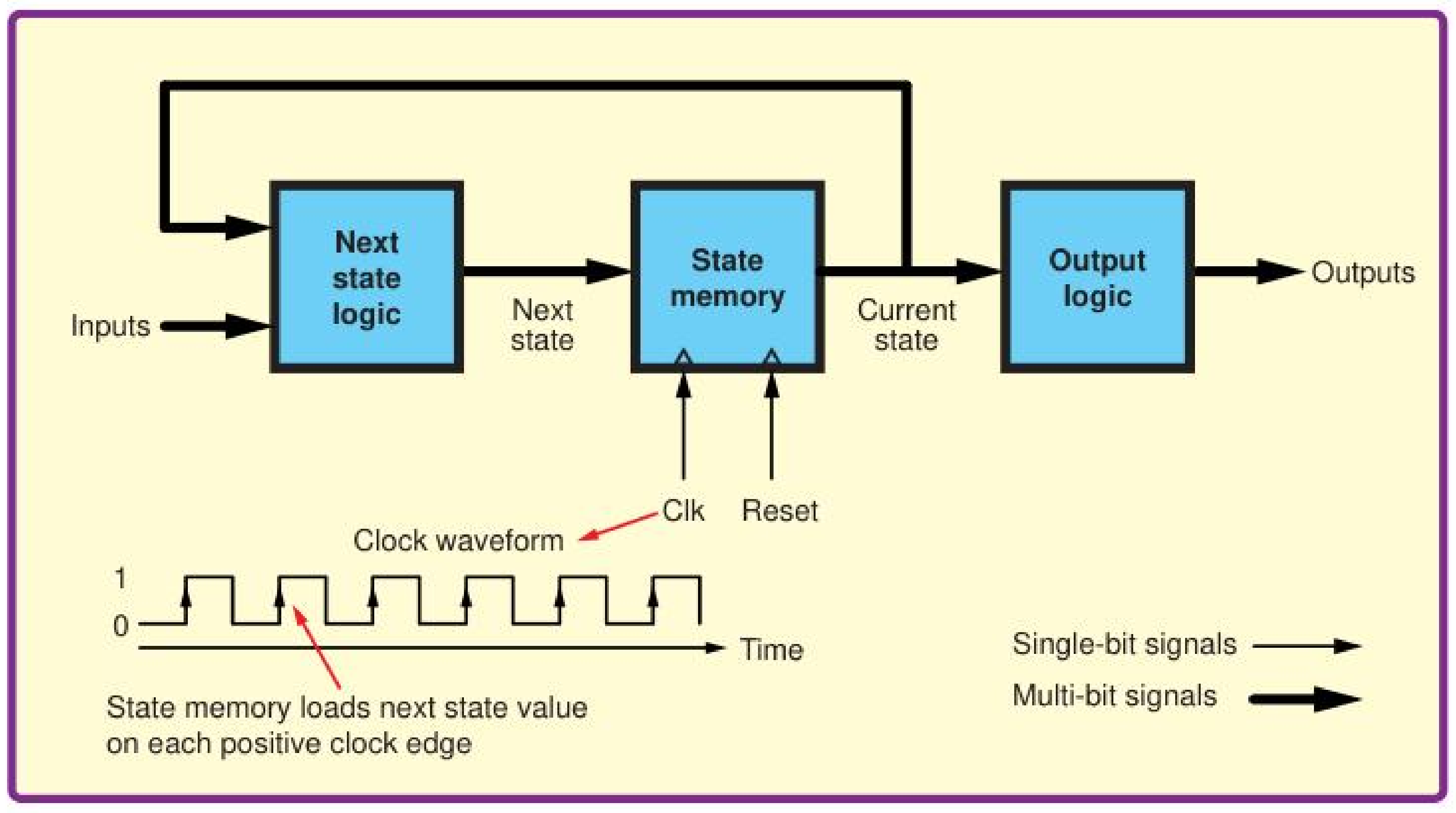


Fig.3. Typical structure of a state machine implemented in digital hardware

These transition conditions are also shown on Fig.2. The state diagram shows the logical conditions for staying in the two states we have just discussed and for completeness we can define this for the other states too. In the case of the clock-setting states this is simply 'Clock-Set button is not pressed', or $\overline{C}$ algebraically. Similarly, the condition for staying in the Oven On state is 'not finished'.

Timing

The exact time at which a digital circuit or software state machine changes state is not necessarily instantly upon a change in one of the input conditions. This might seem to be implied by the discussion so far, and indeed it is possible to trigger state changes directly in response to changes in input conditions. However, in most systems there is an additional timing mechanism that controls when the state changes occur.

In digital circuits this timing is provided by the 'clock' (*not* to be confused with the real-time clock in our microwave oven example) – usually state machines circuits are synchronous, that is controlled by a clock signal (Clk in Fig.3), but asynchronous state machines can be built. The clock signal is a digital square wave and the state machine updates on each positive (or negative) clock edge (0-to-1, or 1-to-0 logic change). The current state is held as a pattern of 1s and 0s in a register – a set of edge-triggered D-type flip-flops.

The input conditions prevailing at the time of each clock edge, together with the current state determine the machine's next state. The new current state (if there is a change) will be established a short time after the clock edge, depending on the delay of the flip-flops. The outputs are obtained by coding/decoding the state bits as required. In some cases the state memory bits can be used directly as the outputs.

In a microcontroller software implementation, the updating of a state machine may be organised in a number of ways. One approach suited to a state machine which is the primary controller of the system is simply to use a 'main loop'. After running initialisation routines, the software loops infinitely, repeating a set of code, including updating the controlling state machine. The rate at which this updating occurs will depend on the execution time of the loop, which may vary depending on exactly what the code does during each iteration. Another approach is to use a timer-driven interrupt to update the state machine at more precisely defined intervals. A third approach is to run the state machine code only when some form of event occurs, such as a change of logic level on an input pin, or receipt of byte by a UART.

Input problems

We have now removed ambiguities in the state transitions from the original state diagram in Fig.1; however, there are still potential problems with this state machine. Consider what would happen if we connected a push switch, wired to produce a logic 1 when pressed (logic 0 otherwise), to the Clock-Set input (C). We will assume an ideal switch without mechanical bounce – although that is another issue we might have to deal with in a real design.

Given that the clock signal (Clk) is likely to be very fast compared to human reaction or switch-pressing time (even if we just jab the switch), the C input will be high for many clock cycles. This will cause the state machine to change state on every clock cycle, jumping from Idle to Set-Hours to Set-Minutes, back to Idle and on to Set-Hours again in a continuous loop until the switch was released. The final state will be random as the user can neither perceive nor control which state the machine will be in when the button is released.

This is clearly not what we want. There are a couple of possible solutions. One approach is to add extra states to the state machine. For example, from the Idle state the C = 1 condition causes a transition to new state which is used to wait until the switch is released (C = 0) before transitioning to the Set-Hours state. While the Clock-Set switch is held the machine would stay in the new state rather than looping through the set of states as previously described. Additional states would also be needed for the other Clock-Set transitions.

An alternative approach is to use an additional circuit between the switch and state machine that produces a pulse of one and only one clock cycle in length when the switch is pressed. To produce a new pulse the switch must be released and pressed again. With this arrangement the original state machine would behave as required. The single-pulse circuit can itself be implemented using a small state machine.

In a software version a similar problem may occur if the state machine simply directly tests the logic level on the C input on each update. Apart from modifying the state machine in the same way, solutions include using an interrupt triggered by a positive edge on the external C input to set a flag, where the flag is actually used as the C input to the software state machine. The flag is reset after the state machine has updated to ensure a single state transition occurs for a single switch press.

Hardware machine structure

Fig.3 shows the general structure of a state machine circuit. The state memory is the data register mentioned above, and the Next State Logic and Output Logic are combinational logic circuits. The State Memory updates every clock cycle by loading the output from the Next State Logic. If the machine does not change state it will simply reload the same value and the Current State will remain unchanged. In the state machine in Fig.3 the outputs only depend directly on the current state – this is a 'Moore machine'. Fig.4 shows the structure of a 'Mealy machine' where the outputs also directly depend on the current inputs.

Table 1. Truth table for the Next State Logic, C2, C2, C0 are the Current State bits, C, U, F, T are the inputs and N2, N1, N0 are the Next State bits

Current state	C2	C1	C0	C	U	F	T	Next state	N2	N1	N0
Idle	0	0	0	0	0	X	X	Idle	0	0	0
Idle	0	0	0	1	X	X	X	Set Clock Hours	0	0	1
Idle	0	0	0	0	1	X	X	Set Oven Timer	0	1	1
Set Clock Hours	0	0	1	0	X	X	X	Set Clock Hours	0	0	1
Set Clock Hours	0	0	1	1	X	X	X	Set Clock Minutes	0	1	0
Set Clock Minutes	0	1	0	0	X	X	X	Set Clock Minutes	0	1	0
Set Clock Minutes	0	1	0	1	X	X	X	Idle	0	0	0
Set Oven Timer	0	1	1	X	X	0	0	Set Oven Timer	0	1	1
Set Oven Timer	0	1	1	X	X	1	X	Idle	0	0	0
Set Oven Timer	0	1	1	X	X	0	1	Oven On	1	0	0
Oven On	1	0	0	X	X	0	X	Oven On	1	0	0
Oven On	1	0	0	X	X	1	X	Idle	0	0	0
Unused	1	0	1	X	X	X	X	Idle	0	0	0
Unused	1	1	X	X	X	X	X	Idle	0	0	0

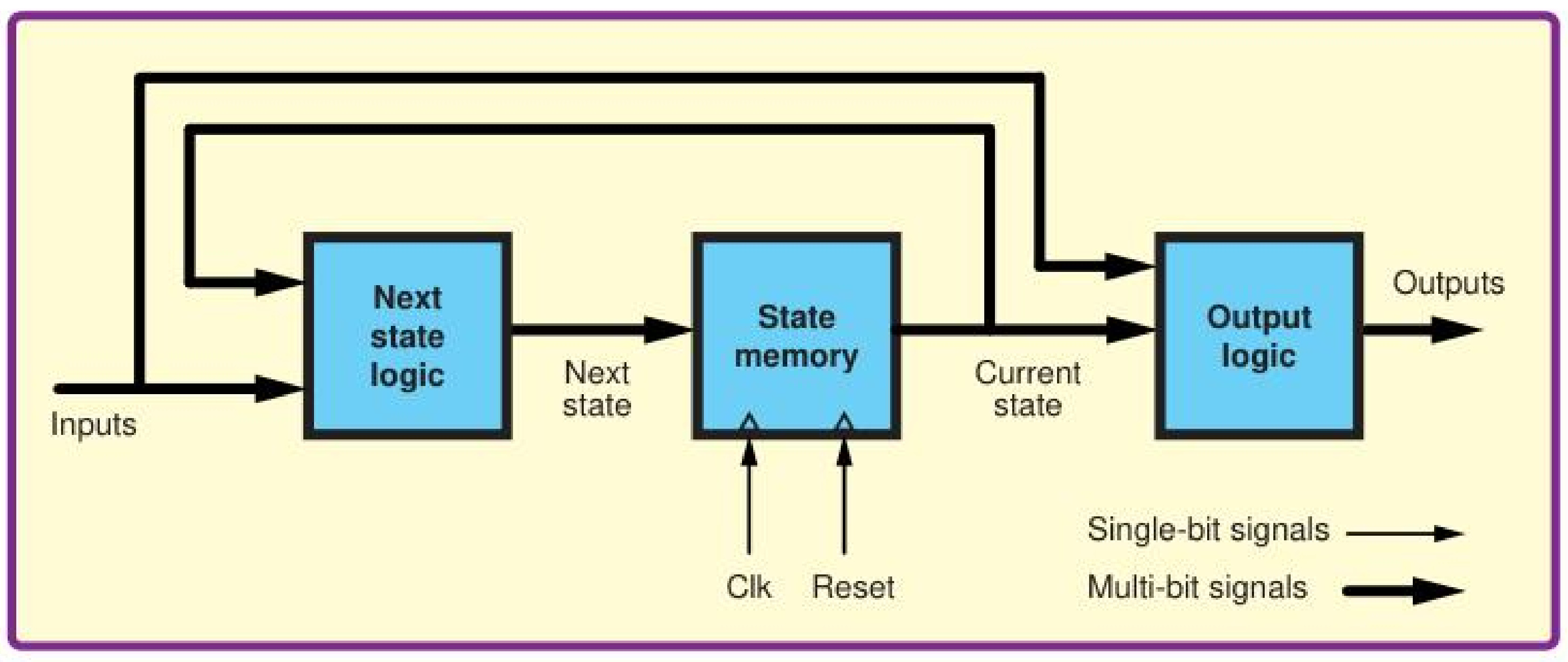


Fig.4. Mealy-type state machine structure

In most systems we will need any state machine circuits to power up into a well-defined state, particularly if the machine is providing overall control and coordination. In the state machine definition we need to indicate what state is entered at reset – this is shown to be the Idle state in Fig.2. In software this will be achieved by appropriate initialisation code. In hardware we typically employ a power-on reset circuit to set up the initial value in the state memory. A reset is shown for the state memory in Fig.3 and 4.

The state diagram implies the Boolean function of the Next State Logic, but in order to actually create a circuit we have to decide on a digital code for each state. For example, for the microwave oven state machine we may decide the Idle state is coded as 000, Set Clock Hours as 001, Set Clock Minutes as 010 and so on. The choice of code for each state is arbitrary, although some choices may provide simpler Next State and Output Logic circuits than others, or even affect the average power consumption of the machine.

In general, the number of state bits required is N, such that 2^N is greater than or equal to the number of states. Our example has five states, so three bits, which provides up to $2^3 = 8$ state codes, are sufficient. Thus, state memory for the example machine requires three flip-flops. With a possible eight state codes and five used, there will be three unused codes.

State table

Once we have defined the state codes, we can combine this with the definition of the machine's behaviour from the state diagram to completely enumerate all combinations of the Current State code and the inputs, defining the corresponding Next State in each case. This produces a state table (see Table 1) which is a truth table for the combinational logic of the next state circuit. In fact, for our five-state example, with its three-bit state code, the state table defines three combinational logic circuits, one for each state bit. We can also produce a truth table for the output logic – this defines the logic level of each output in every state.

Note that the state table includes the unused states; although these should never occur during operation. However, in order to define sensible behaviour, we set the next state for all unused states as the Idle state, irrespective of the inputs.

As our example has four inputs (C, U, F, T) and a three-bit current state (C2, C1, C0) the Next State Logic has a total of seven inputs, which provide a possible $2^7 = 128$ combinations of 0 and 1. Clearly, Table 1 does not have 128 rows; this is because we made use of the cases where particular inputs do not influence the next state, given the values on the other inputs. There are referred to as 'don't cares' and are represented by an 'X'. For example, the first

Listing 1: Partial sketch of C code for state machine in Fig.2

```
enum machine_state {Idle, SetMin , SetHour , SetTimer, OvenOn}
CurrrentState = Idle;
enum disp_func {Clock, Timer} DisplayMode = Clock;

// Get the values of ClockSwitch, ControlUp,
// Finished and TimeOut from the hardware
GetInputValues();

switch (CurrrentState)
{
        case Idle:
                if (ClockSwitch)
                {
                        CurrrentState = SetHour;
                }
                else if (!ClockSwitch && ControlUp)
                {
                        CurrrentState = SetTimer;
                }
                // Display clock, all other outputs off
                DisplayMode = Clock;
                SetMinutes = 0;
                SetHours = 0;
                OvenPower = 0;
                break;

        case SetHour:
                if (ClockSwitch)
                {
                        CurrrentState = SetMin;
                }
                // Display clock, enable hour adjust on clock
                DisplayMode = Clock;
                SetMinutes = 0;
                SetHours = 1; // Hour adjust enabled
                OvenPower = 0;
                break;

        // remaining state machine code here

        default: // We should never get here!
                CurrrentState = Idle;
                break;
 }
```

row defines the conditions for staying in the Idle state. The Timeout (T) and Finished (F) inputs are irrelevant here as transitions out of the Idle state are controlled only by the Clock-Set (C) and Up (U) inputs. The first line of Table 1 represents four lines of the fully expanded truth table, covering all possible combinations of F and T (00, 01, 11 and 10).

Logic Friday

The state table fully defines the combinational logic circuit of the Next State Logic. But actually creating the circuit in terms of AND, OR, NOT gates may be quite difficult. The well-known Karnaugh map approach is not easy to use for more than four inputs.

Fortunately, software tools can come to the rescue, with the Logic Friday freeware (**sontrak.com**) being one possibility. Logic Friday employs the Espresso logic minimisation algorithm, which was originally developed at IBM and later published in 1986 by Richard Rudell at the University of California, Berkeley. The truth table (including don't-care Xs) can be imported into Logic Friday by writing a text file in the required format. The software can then produce minimised logic equations and even a logic circuit schematic. However, it may be possible to produce better circuits manually, directly from the minimised logic equations.

Implementing this logic in 4000 or 74 series logic would be quite messy and require quite a few chips – see the large logic boards of early digital computers! This certainly seems to make the microcontroller/software option look very favourable. However, as indicated last month, a better approach (if using hardware) would be to employ a single programmable logic device (PAL, CPLD, FPGA) for the whole state machine – and other logic in the system too. The design tools associated with these devices may provide assistance for creating state machines.

Software implementation

As mentioned by ***atferrari*** in his post on this topic, the code for a state machine in C (and other languages, including hardware description languages such as VHDL) is often based around a switch statement. A switch statement is simply a neat way of writing a long set of `if` statements of the form:

```
if x=1 then
      do thing 1
if x=2 then
      do thing 2
if x=3 then
      do thing 3
...and so on
```

In the case of a state machine x is the current state and the 'things to do' are to set the next state and outputs.

Listing 1 is a sketch of part of some C code for the example state machine, which illustrates the structure of typical state machine code. This is far from a complete implementation and does not attempt to show how the interface to hardware (microcontroller I/O pins) is implemented, or even include declarations of the all variables. The switch statement is shown for just two of the states – the others will follow the same pattern. Note the use of an `enum` (enumeration type) to define the state code. We assume this code is called regularly in a main loop, or timer interrupt, as discussed earlier

In his post ***atferrari*** mentions that the use of a switch statement seems crude. It is perhaps verbose and repetitive, and in some cases the functionality could be implemented in fewer lines of *ad hoc* code. However, the switch statement and state machine approach produces code that is well structured and therefore easier to debug and maintain.

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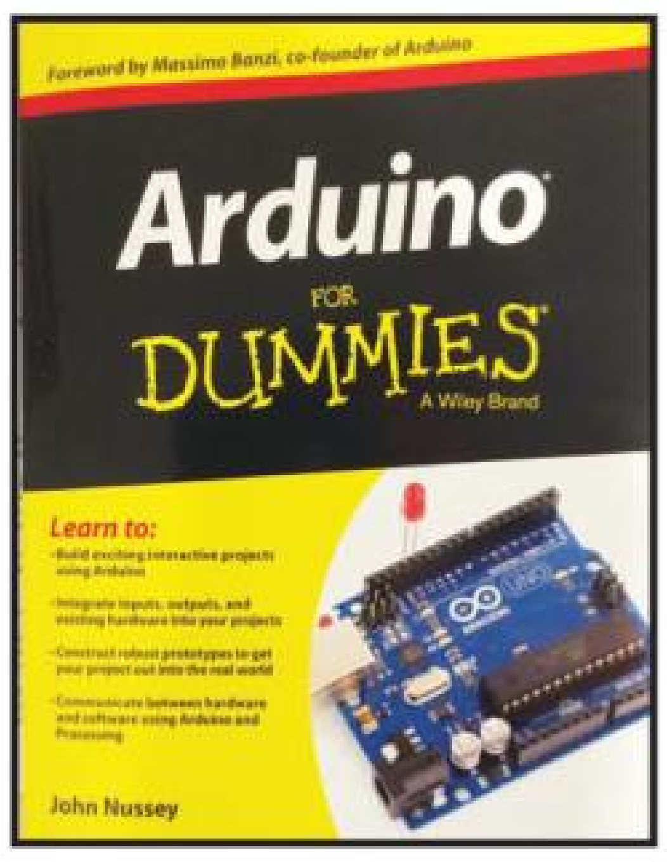

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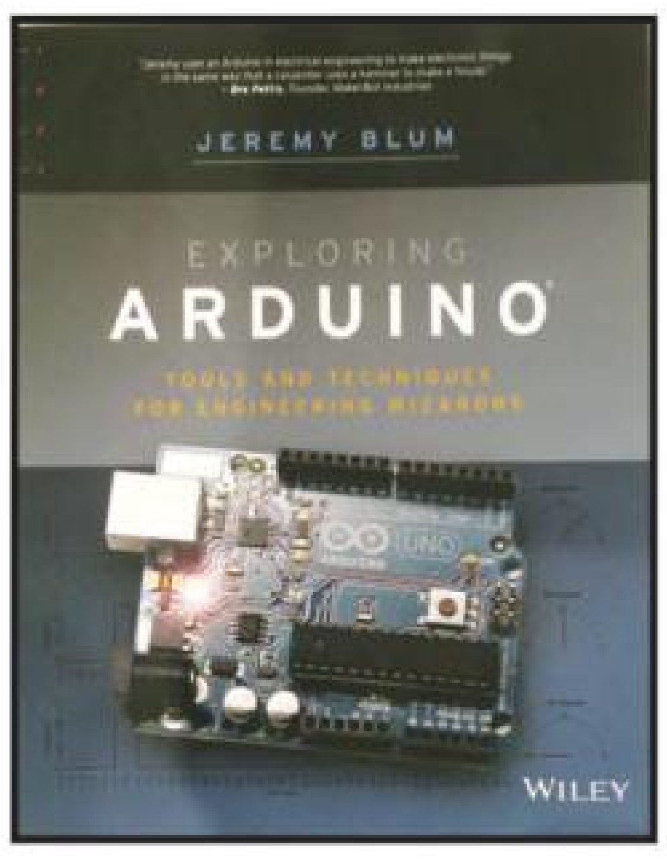

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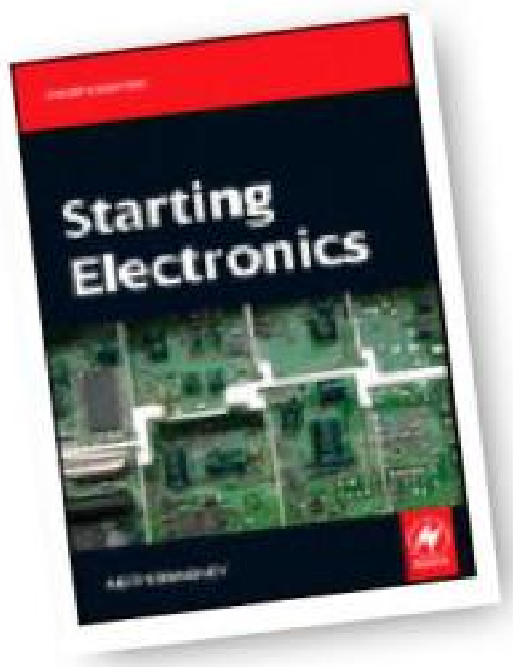

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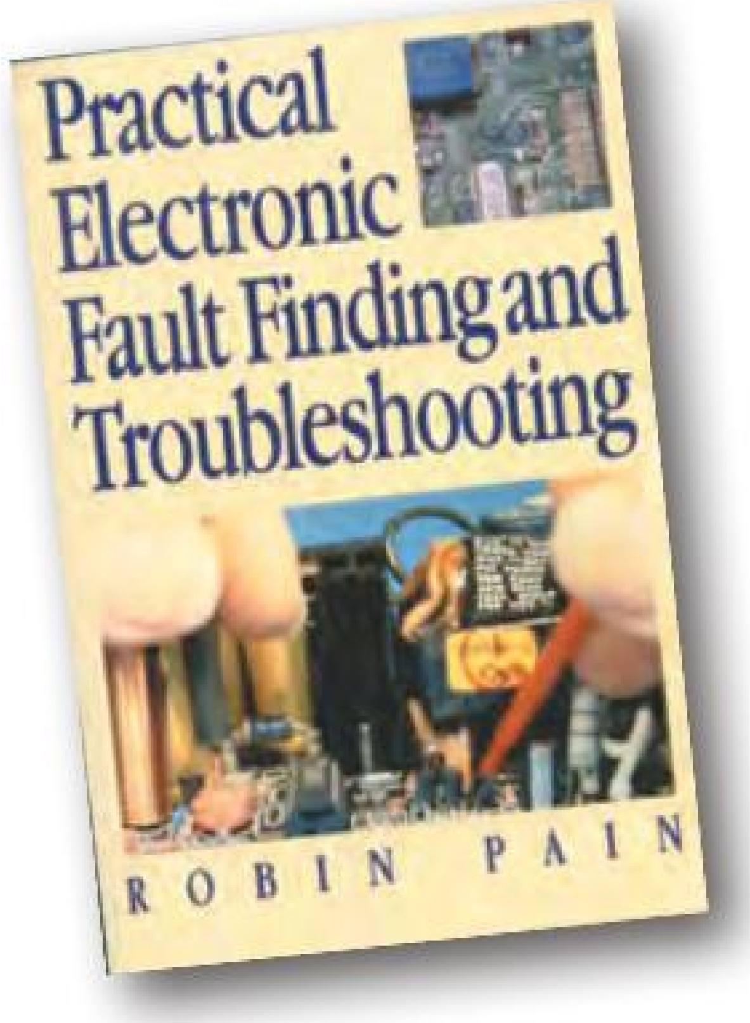

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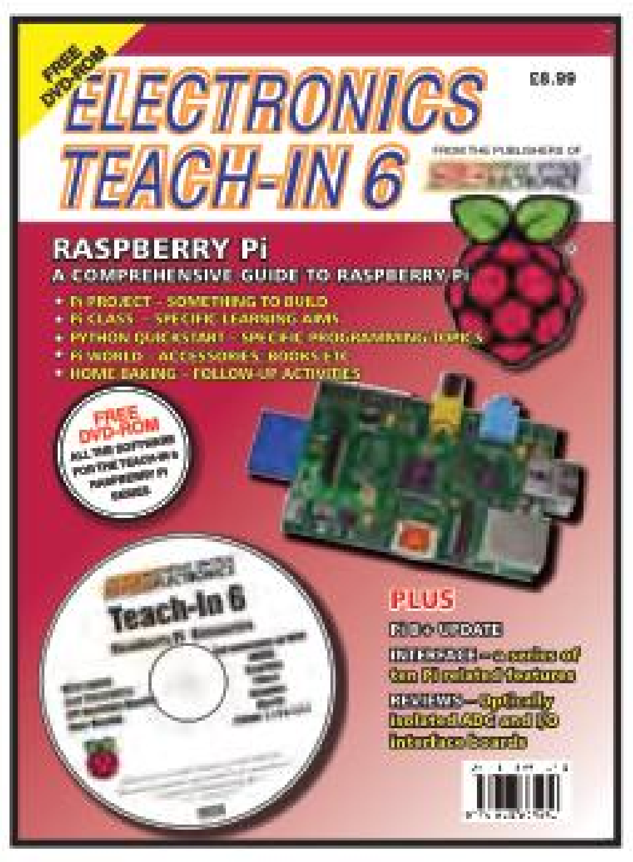

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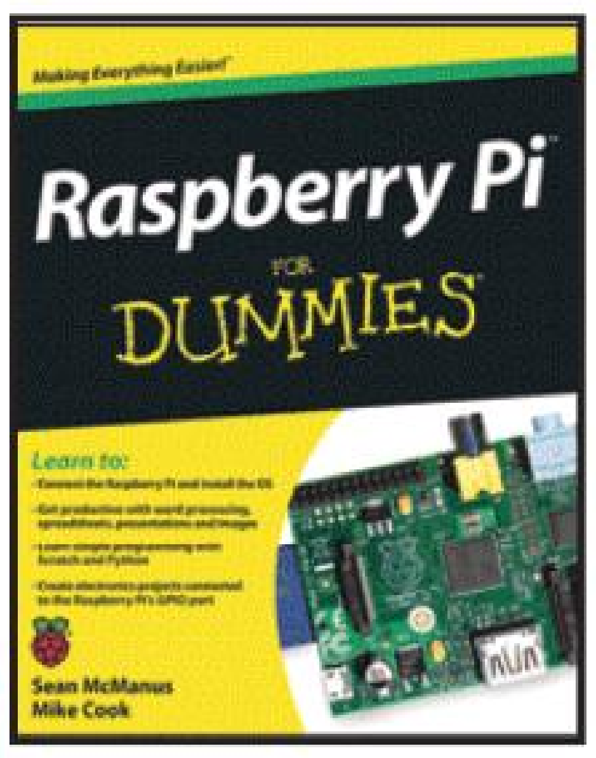

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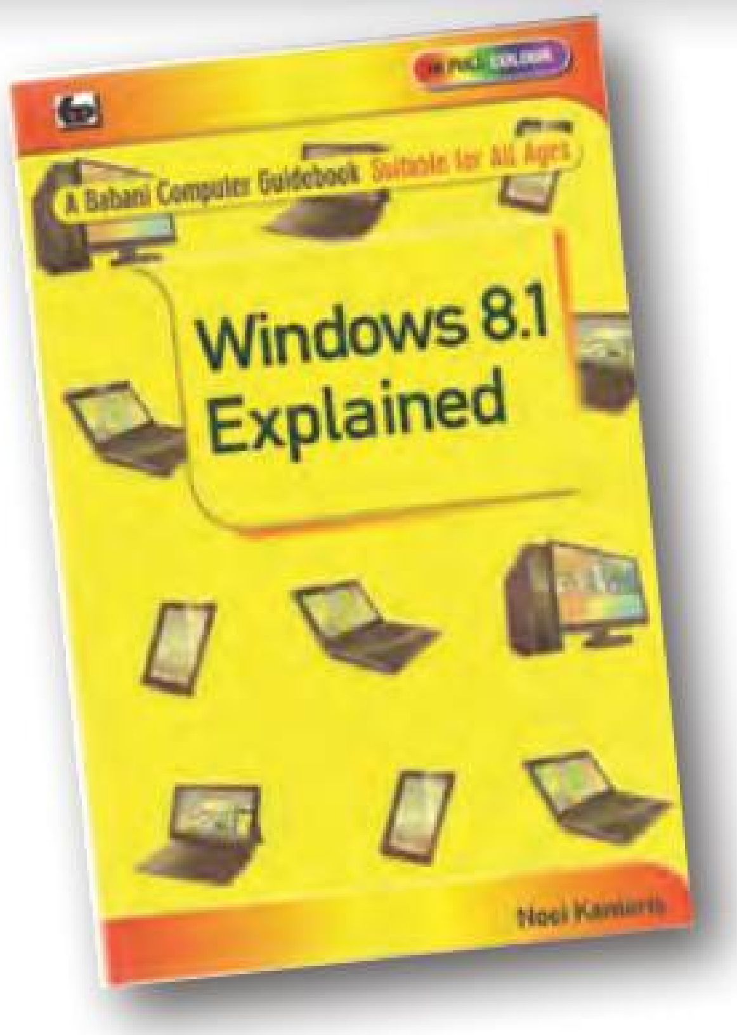

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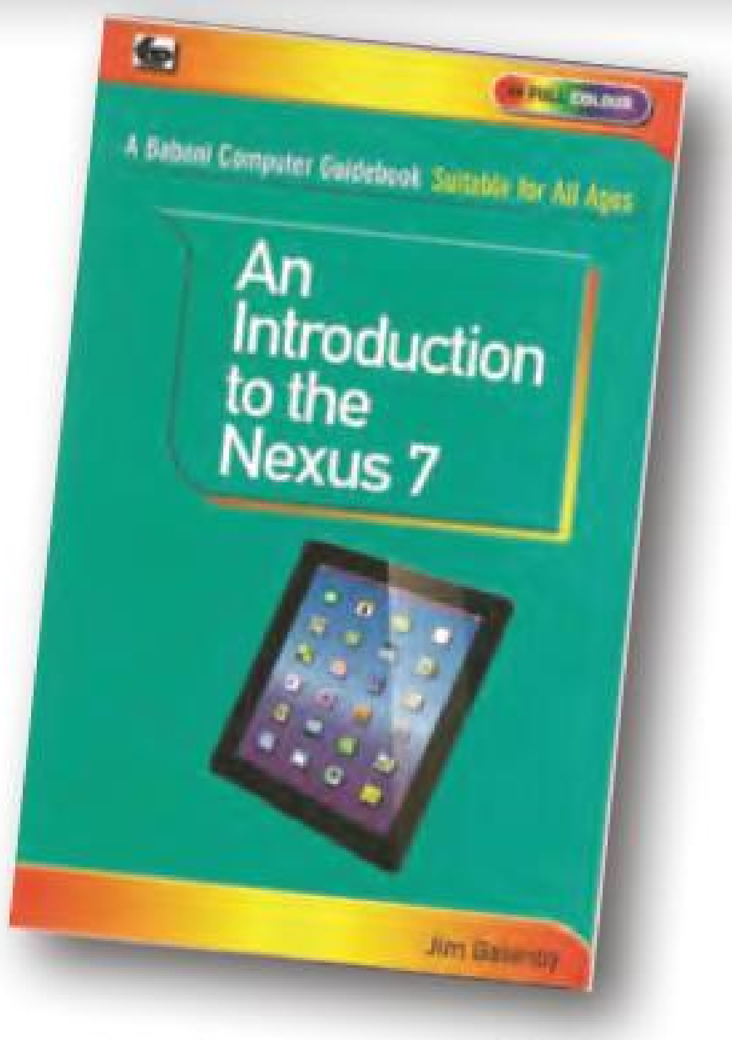
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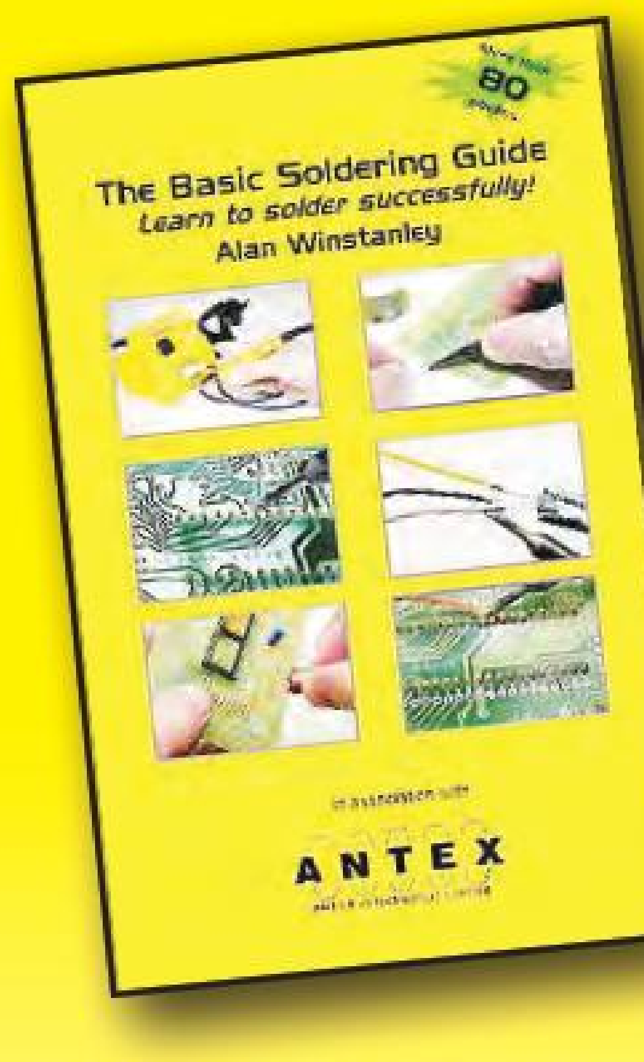

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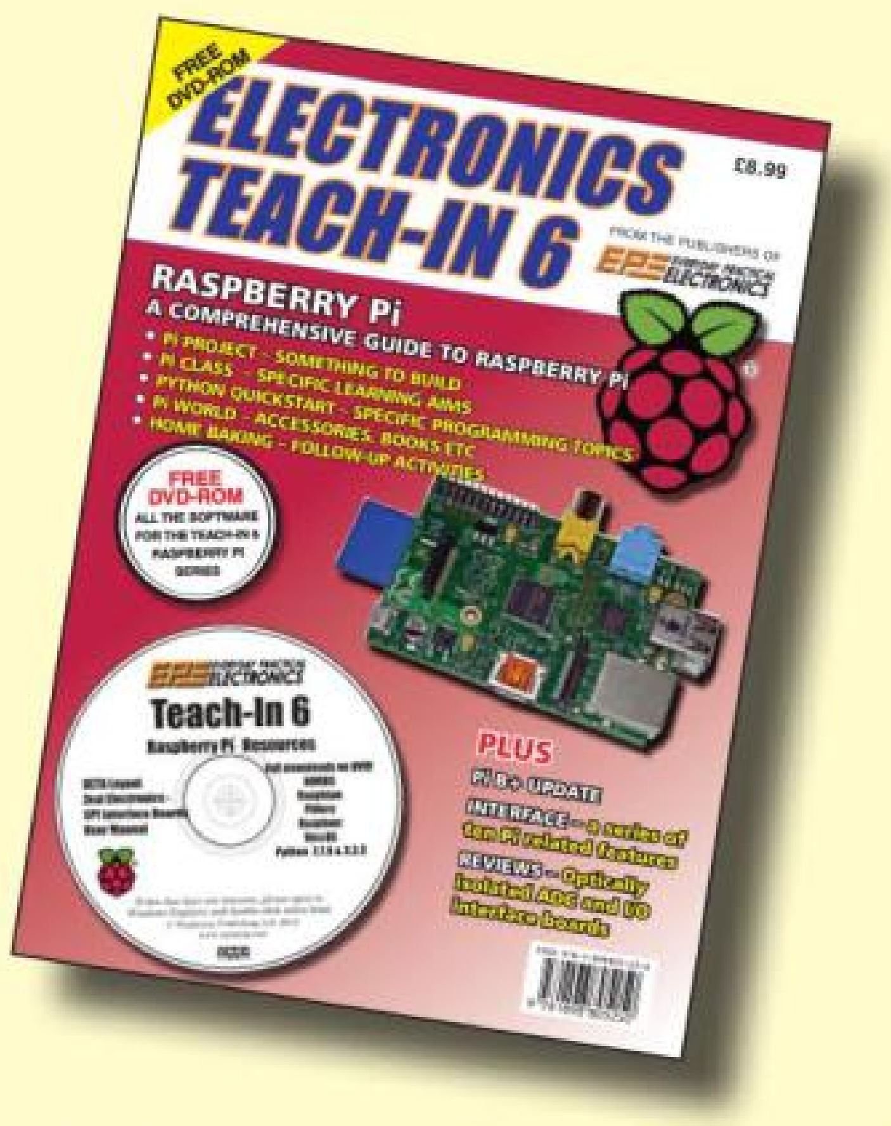
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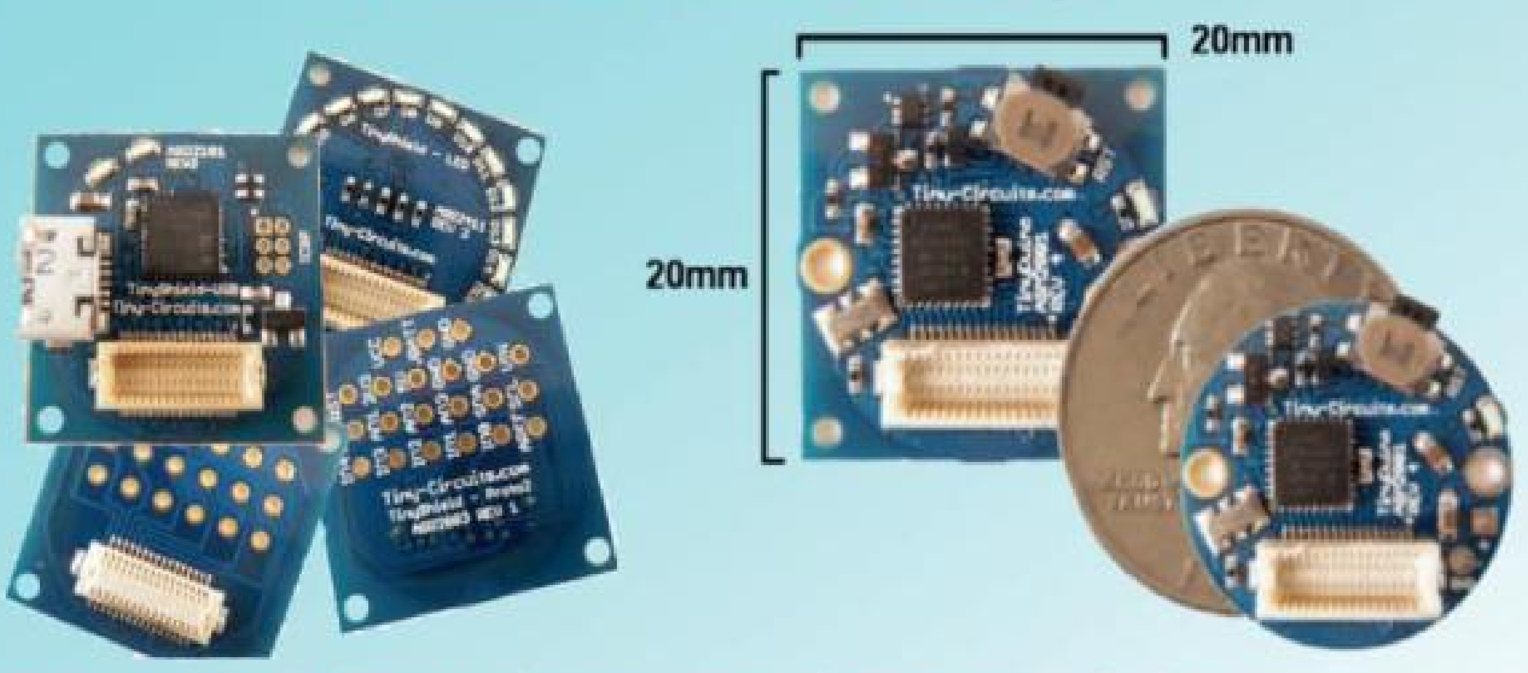

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Max's Hot Beans

By Max The Magnificent

Have that scribe washed...

...and sent up to my room! Before we plunge headfirst into the fray with gusto and abandon, I'd like to take a moment to bemoan the dire state of documentation that seems to accompany (or not, as the case might be) so many of today's electronic products.

I remember a time when even a humble component data sheet was the size of a small novel and came equipped with a wealth of details on how to deploy the part, including exquisitely detailed example applications. I don't wish to cast aspersions (my throwing arm isn't what it used to be), but it seems that the folks who supply electronic devices these days have little interest in explaining how to actually use them. It may be they assume that anything one needs to know is available on the Internet, but is it really the end-user's responsibility to painstakingly track this information down? The reasons for my disgruntlement and my mentioning this here will become apparent as we proceed...

Testing times

A few weeks ago, while I was happily ambling around the building in which I rent my office, I came across two of my chums – Ivan and Darryl – excitedly experimenting with a small piece of equipment with which I was not familiar. This little scamp turned out to be an incredibly clever component tester that Darryl had picked up on eBay for only $20 with $0 shipping and handling (**http://ebay.to/1QF3pe6**). Well, I was so enthused by what I saw that I raced back to my office and ordered one of my very own – see exhibit A in Fig.1.

This really is very tasty – if I were in the habit of wearing a hat, I would doff it to whoever came up with the original idea. The heart of the system is a cheap and cheerful microcontroller augmented with a smattering of discrete devices. You take your component to be tested and insert it into the ZIF (zero insertion force) socket. The component can have two leads (resistor, capacitor, inductor, diode) or three leads (potentiometer, bipolar junction transistor, or field-effect transistor), and you can plug it into the ZIF socket any way you wish (more on this later). You don't even have to tell the tester what type of component you've plugged in – it works this out for itself. Once you've inserted the component, you press the 'Test' button and leave the tester to perform its magic. After a couple of seconds, it tells you what sort of component you have, the values associated with that component, and which leads are plugged into which ZIF socket pins.

In Fig.1. I used a 10µF ceramic capacitor with which to perform a quick test. Since this is a non-polarised component, the graphic depiction on the screen doesn't differentiate between the pins. By comparison, if you are testing a polarised component like an LED, the system correctly associates the appropriate pin numbers with the anode and cathode terminals. Similarly, in the case of a transistor, the system will automatically determine whether we are talking about a BJT or a FET and identify the terminals and suchlike.

One thing that did puzzle me for a while was the pin numbering convention. Everything seemed to work as expected when I plugged my components into any combination of pins 1, 2, and 3 in the ZIF socket, but things started to get weird if I used any other pins.

This is where we come to the fact that

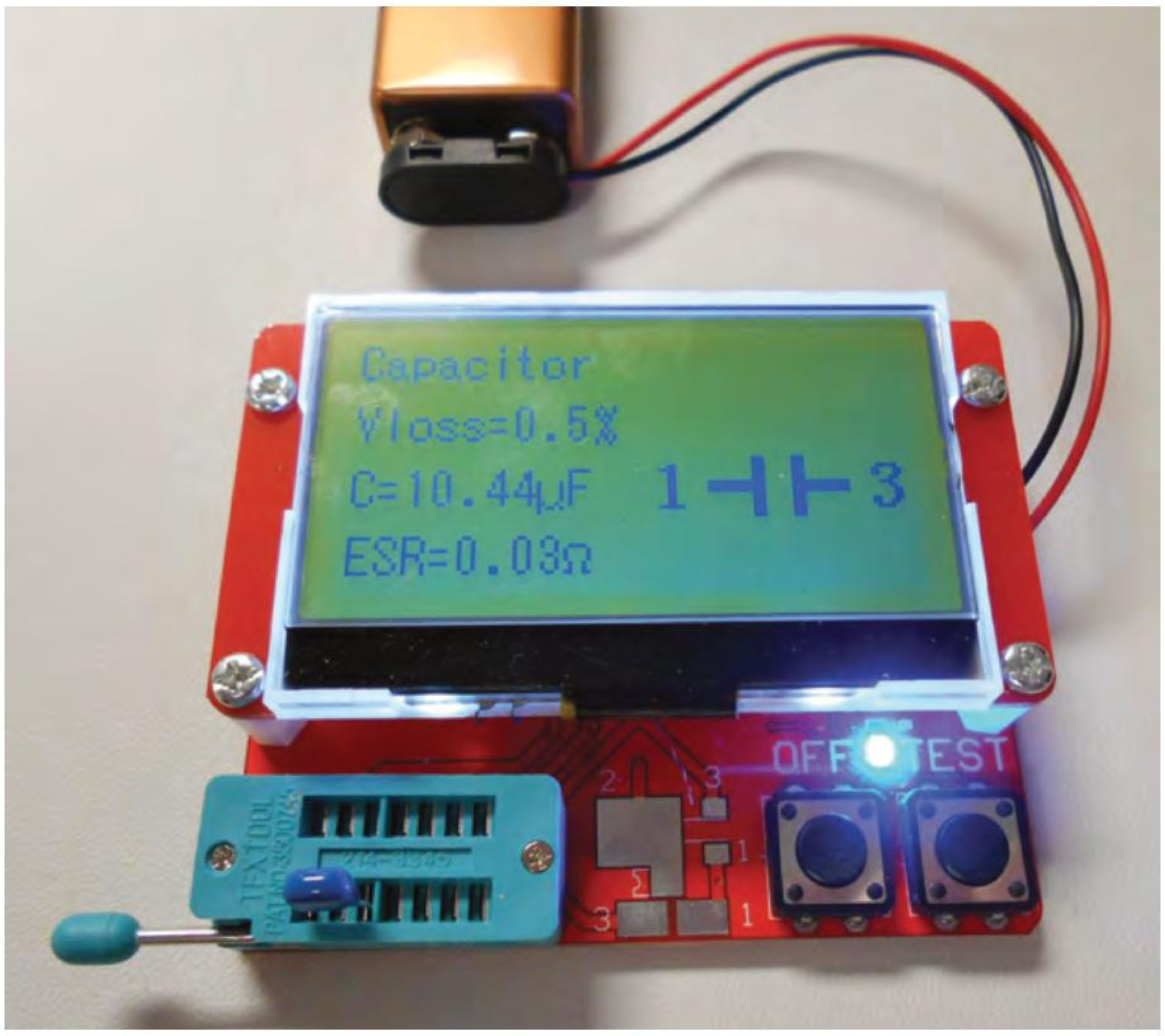


Fig.1. This little beauty tests resistors, capacitors, inductors, diodes, and transistors (BJT or FET)

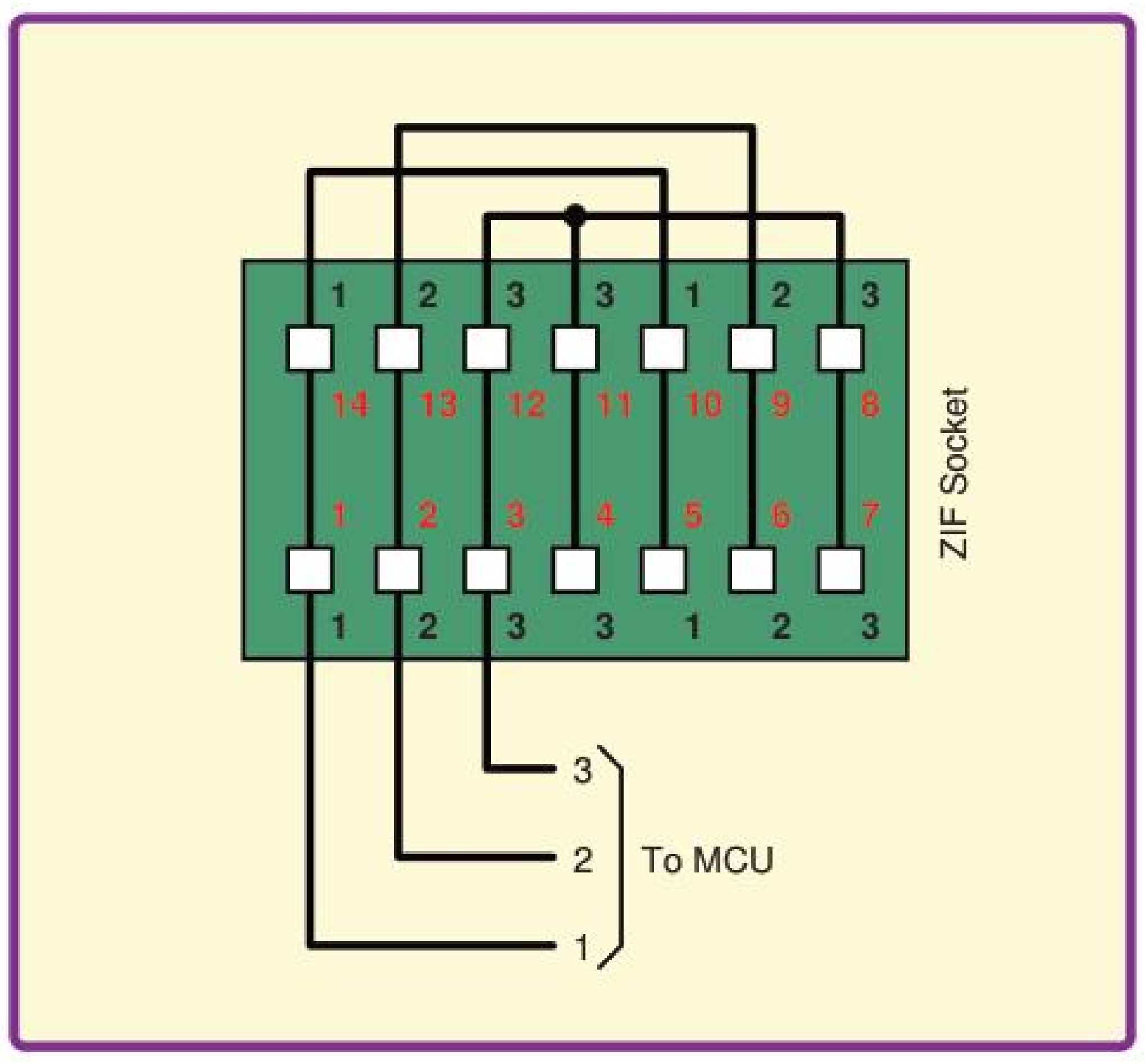


Fig.2. Pin-numbering convention

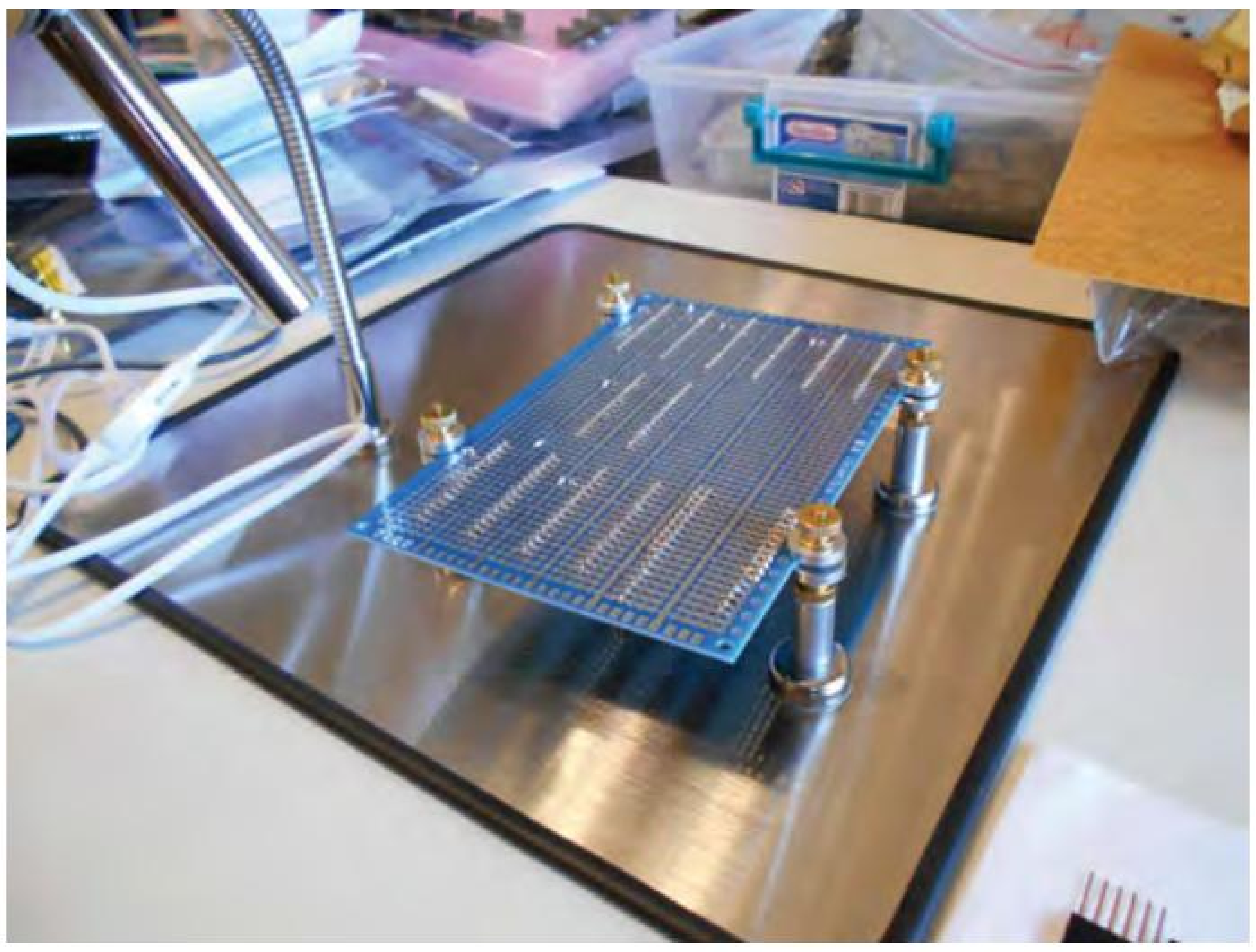


Fig.3. The POLUS soldering and inspection station

some (any) documentation – even a post card-sized quick-start – would have been very much appreciated. I had originally assumed that the ZIF socket pins would be numbered like an IC, with 1 through 7 from left to right on the near side and 8 through 14 from right to left on the far side. It was several days before I spotted the annotation '1233123' on the silkscreen skulking behind the ZIF socket. I eventually came to realise that this is intended to indicate that the ZIF socket pins are numbered/connected as illustrated in Fig.2 (note that there are a variety of these testers available on the market, and each may sport a different pin-numbering scheme).

Of course, a very important question would be 'Just how accurate are these testers?' Well, out of the box as compared to a professional grade unit, the resistance was off by only 0.3Ω, for example, which is 'close enough for government work,' as they say. Furthermore, if you short pins 1, 2, and 3 together and then press the 'Test' button, the system automatically enters its calibration mode. Once again, there is no documentation to inform you of this invaluable nugget of knowledge. The only way I discovered this myself is that Ivan and Darryl told me – and the only way they unearthed it was that they are the sort of people who say to themselves 'I wonder what would happen if we shorted pins 1, 2, and 3 together before activating the tester?'

The bottom line is that I can no longer recall life without having my trusty component tester close to hand. As far as I'm concerned, it would be worth the money if all it did was test capacitors (I have hundreds of the little rascals laying around because I cannot read their markings) – the fact that it also works with resistors, inductors, diodes, and transistors is cream, cherries and little bits of chocolate on the cake.

The years have not been kind...

I remember way back in the mists of time when I was a bright-eyed, bushy-tailed young lad and I could actually see what I was soldering. I've always been short-sighted (I need glasses for distant viewing), so I could easily see the solder joints. Alas, the years have not been kind, and I'm finding it harder and harder to spot shorts and dry solder joints – the only saving grace is that I've been doing this so long that I have the 'knack' (**http://bit.ly/24q31db**) and rarely get either.

Having said this, it can be a real pain trying to track problems down when you can't see what you're doing. Thus, I was jolly excited when I ran across a very affordable (~$105 including shipping and handling) soldering and inspection station called 'POLUS' on Amazon (**http://amzn.to/1O0PMX3**).

As illustrated in Fig.3, the POLUS boasts a stainless steel base and four board holders that look a bit like chess pieces. The board holders, which can be adjusted to any board thickness from 0.1 to 5.0mm, attach to the base magnetically, which means they can be placed anywhere on the base and they can accommodate any board shape and size up to 400 mm.

To the left of the board in Fig.3 we see a tall, flexible, magnetically attached stand. Although it's not terribly clear in this image, this stand is holding a USB microscope (the silver tube appearing in the upper-left corner of the photograph) featuring a two-megapixel CMOS sensor with a 10 to 500x optical zoom that supports 1600 x 1200 resolution images and videos.

Once again, however, this little scamp arrived without any form of documentation excepting a link to a website. I don't actually recall what I did (I've not been able to repeat the experience), but somewhere I tracked down the required application and documentation for my PC. On the bright side, the USB microscope works like a charm, as shown in Fig 4.

On the downside, the documentation leaves something to be desired (translating it into English would be a start!). For example, I've still not successfully managed to use the microscope to capture a still image – instead, I've been reduced to taking screenshots. Having said this, I rarely need to actually capture an image – I'm more interested in seeing the live image on my computer screen.

So, the bottom line in this case is that I am more than happy with my purchase and I firmly believe that this little beauty is going to be worth its weight in gold over the years to come. Until next time, have a good one!

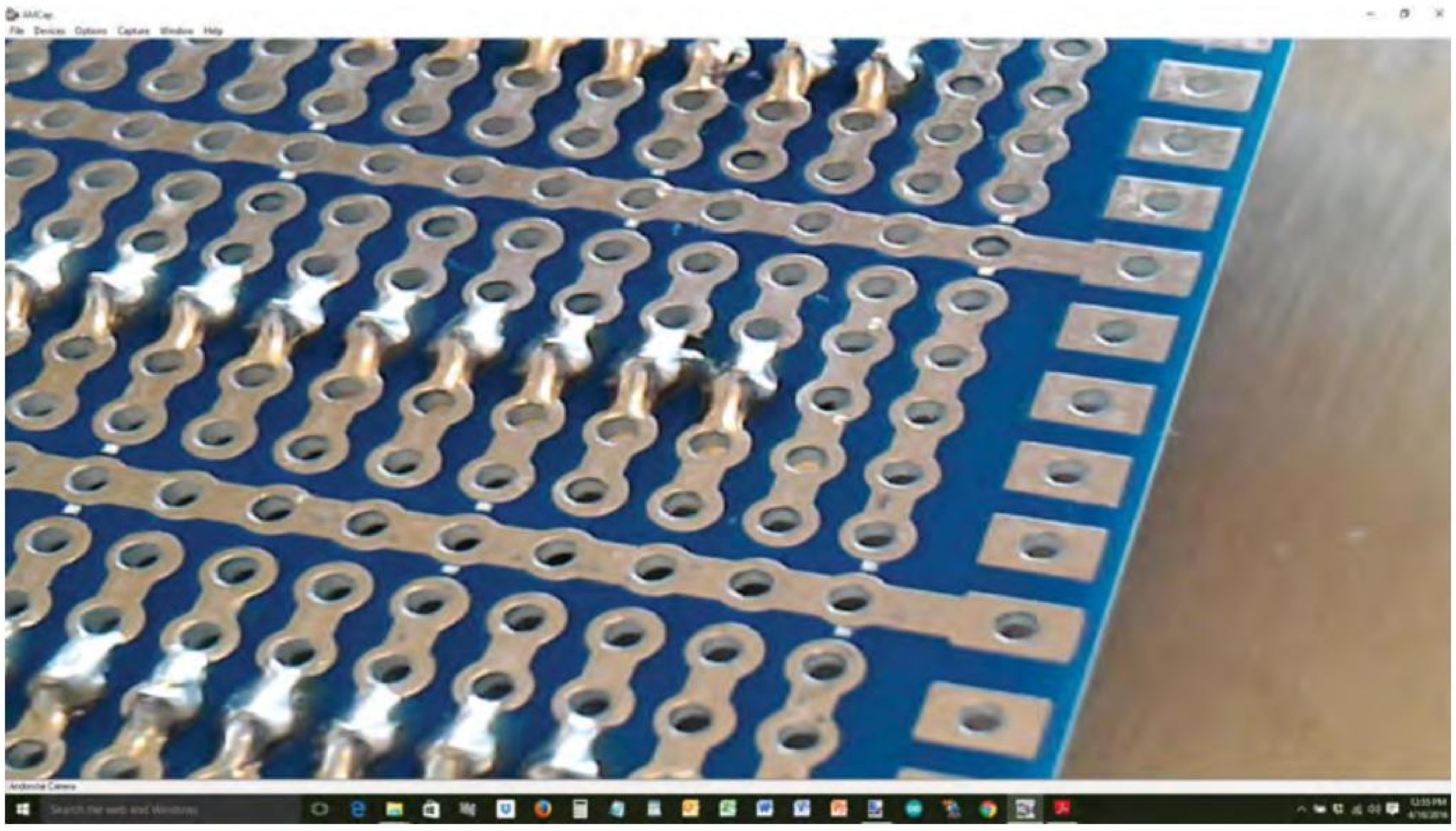
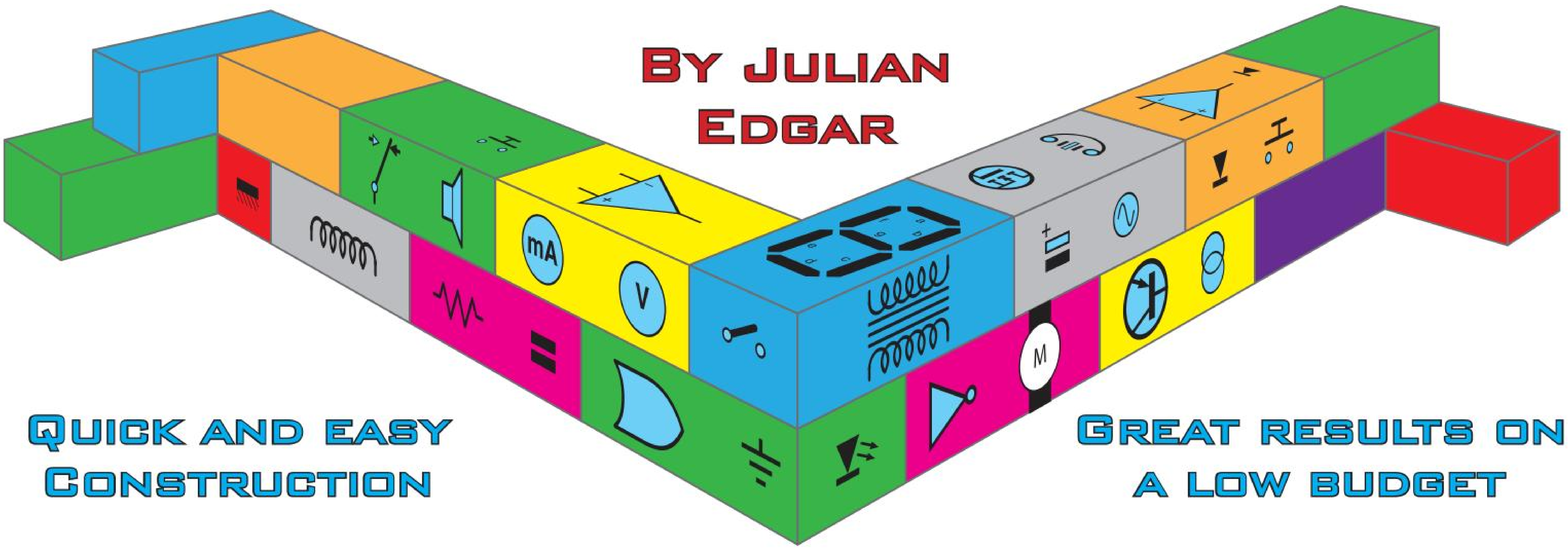


Fig.4. Screenshot of the USB microscope app showing a board I'm soldering

Any comments or questions? – please feel free to send me an email at: **max@CliveMaxfield.com**

Electronic Building Blocks



By Julian Edgar

Quick and easy construction

Great results on a low budget

Hand-powered LED torch

Large complex projects are fun, but they take time and can be expensive. Sometimes you just want a quick result at low cost. That's where this series of *Electronic Building Blocks* fits in. We use 'cheap as chips' components bought online to get you where you want to be... FAST! These projects range from around £15 to under a fiver... bargains!

Not what it seems!

This project is good fun and you end up with a useful torch that will never get flat batteries and will last a very long time. However, at first sight, this might not seem like my traditional 'EBB' project – 'where's the cheap-as-chips Chinese circuit board', I hear you cry? Well, it's true, this month does resemble my previous recycling column. In fact, it's probably best described as a hybrid between the two. So bear with me, and while this little project may be billed as a 'torch', what I am really giving you is a mini-generator building block made from recycled parts that you can use whenever you need some free-ish electrons. Do you fancy building a wind-up radio or USB charger? This project will get you over the hump and well on your way.

Introduction

These days, hand-powered LED torches are available at quite low prices. They typically use internals that comprise a geared-up generator or alternator, rechargeable battery and high-efficiency LED. But the trouble with these designs is that they're often cheap and nasty – the plastic gear-train is noisy and wears out quickly, and the battery ceases holding charge after only a short time.

So why not make your own hand-cranked LED torch? If you salvage a few parts from other equipment, or source some components cheaply on eBay, you can make a torch that will last for many years. In fact, I made one of the torches shown on these pages over ten years ago. I use it whenever I need to move around inside the house after dark, so over that time it has been used thousands of times. And the torch is particularly good at this function – it's not so bright that you're blinded, but still easily bright enough to go to the bathroom, raid the fridge or check on a sleeping child.

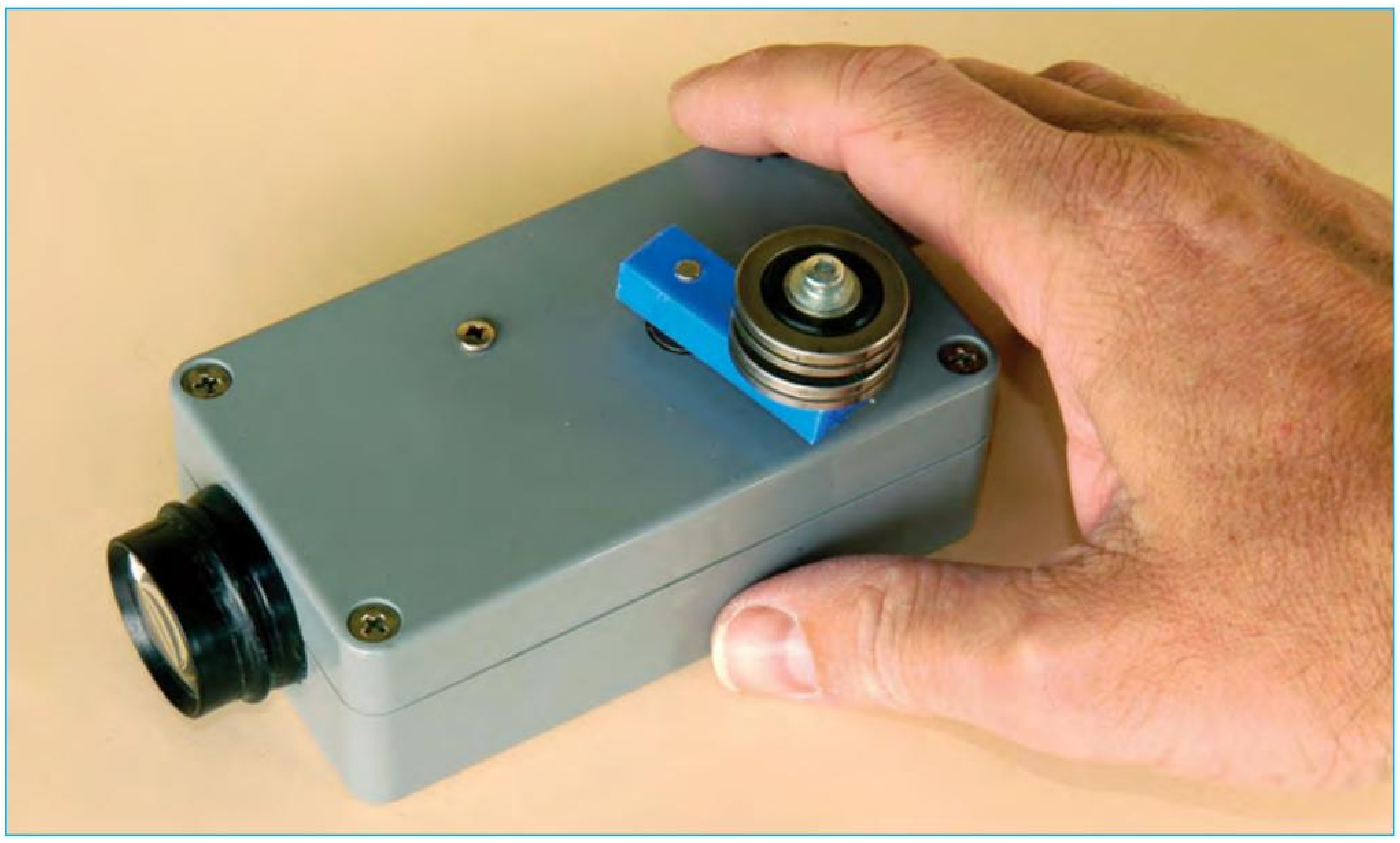


Fig.1. This hand-cranked LED torch is over ten years old. Despite being used almost nightly, it still performs well. This design uses a stepper motor salvaged from a printer as the power source. Optics give a focused beam and are taken from a discarded camera. Note the ball-bearing knob on the handle – another salvaged part from a printer.

There are three basic designs that I use for these torches. The common aspects of all these designs are the capacitor bank and LED.

Capacitor bank

Each torch design uses a bank of capacitors to store the power. These capacitors need to be small enough to fit inside your chosen box, while still having a large capacitance. They also need a voltage rating of about 10-16V. For example, two, four or eight 10,000µF 10V capacitors are ideal, but it doesn't matter if you use 10,000µF 16V caps instead.

While at first it might seem a good idea to use a 'super capacitor' of say one farad capacity, in practice that doesn't work particularly well. Why? Well, charging-up a one-farad capacitor will take a great deal of winding of the handle before the LED even lights.

I size the capacitor bank so that the LED doesn't change noticeably in brightness as you are cranking the torch, and the LED stays bright enough to be useful for at least 30 to 60 seconds after you stop cranking. In practice, that works well.

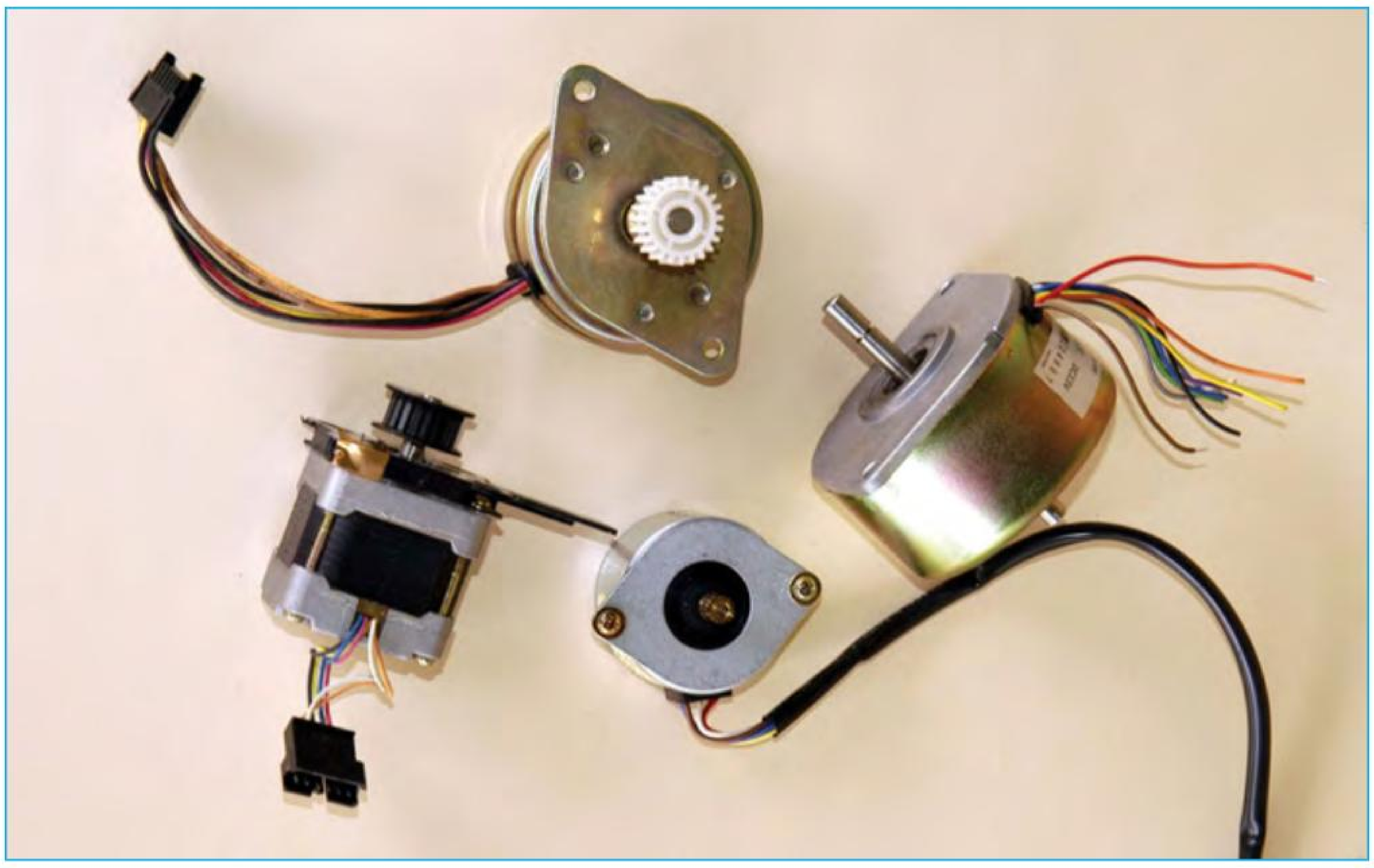


Fig.2. These are the sort of stepper motors that can be used as the power source in a hand-cranked LED torch. Stepper motors are direct-driven by a knob or handle and give quiet, reliable power.

LED

Any high-efficiency white LED will work well in a hand-cranked torch. While in the past I have used high-power LEDs (eg, a 1W LED), the required size and weight of the generator then increases considerably, as does the requirement for a large capacitor bank. It is simpler and easier to keep the LED power requirements low.

I also use a dropping resistor to limit peak current to the LED. You may think that this would be a good spot to insert a constant current supply board (eg, a buck/boost design) but a simple resistor gives safety for over-fast winding, and allows the LED to dim gradually as the capacitor voltage declines, rather than cutting off the LED abruptly.

In fact, it's easiest to pick a high intensity 5mm white LED, pre-wired with a dropping resistor for working from 12V. (Most systems end up with a voltage at the capacitors of about 10-12V.)

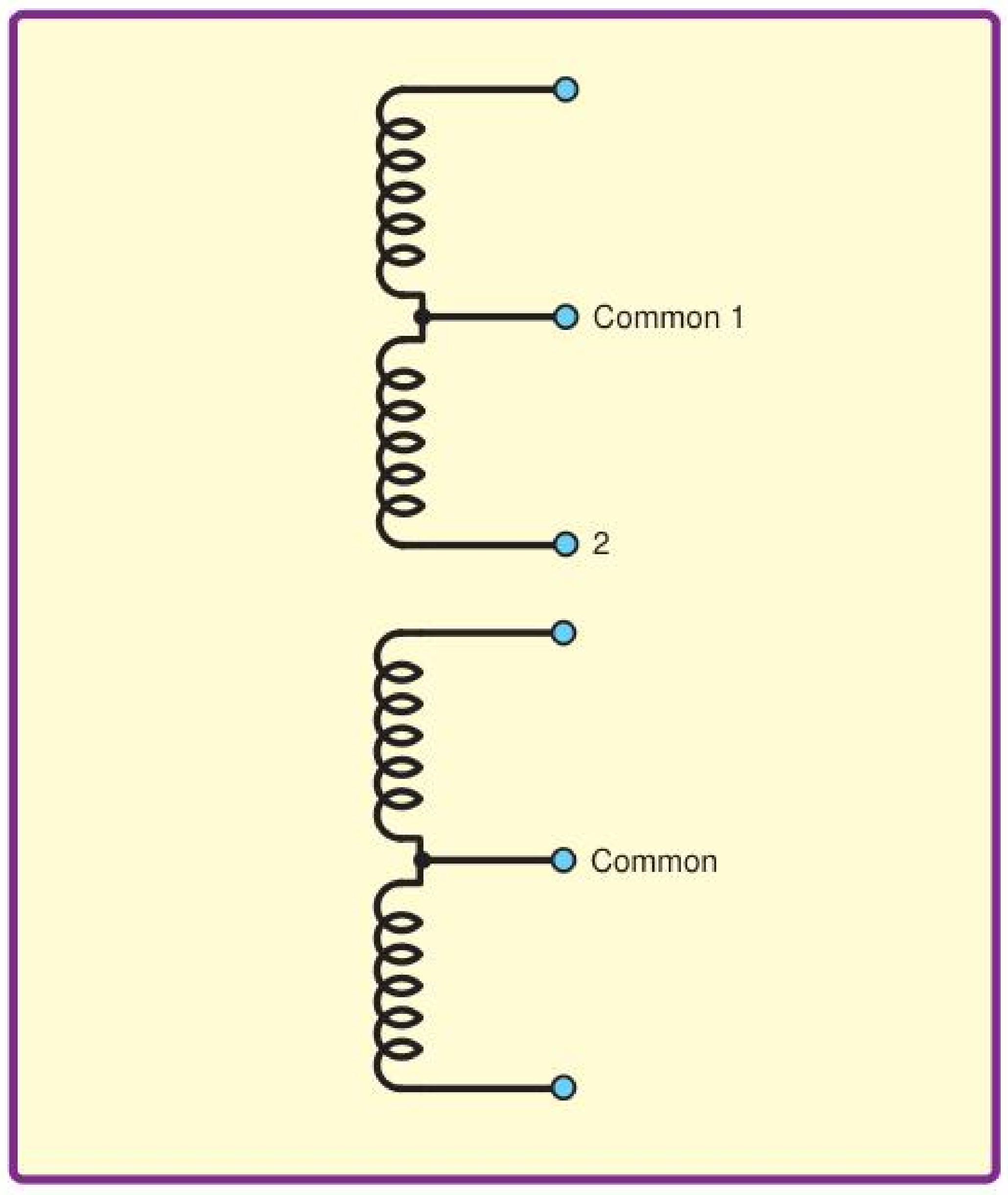


Fig.3. Six-wire stepper motors are configured like this. Use a multimeter (set to resistance) to work out which wire is which.

Three different power sources

Three different power sources can be used; let's look at each in turn:

- Stepper motor being direct-driven as an alternator
- DC motor with integral gearbox (preferably of the planetary type) driven backwards as a generator stepped-up in speed
- Microwave oven turntable motor plus gearbox, driven backwards as an alternator stepped-up in speed

Stepper motor

Stepper motors, such as the ones in Fig.2, can be salvaged at zero cost from old electric typewriters and printers, or bought new cheaply. They work well as direct-drive alternators in hand-cranked torches. In use they are silent, and in this application they will last forever. The downside is that many will not develop enough power at the rotational speed you'll achieve with only a knob or handle on the shaft. (If you can find a stepper motor with a high quality step-down gear-train built in, it will make an ideal power source for a hand-cranked torch. However, these units aren't common.)

So how do you select a suitable stepper motor? First, pick one that is decently sized, for example, 50mm in diameter. Most steppers of this size will be six wire designs, with, as Fig.3 shows, two electrically separate centre-tapped windings. Use a multimeter to measure the resistances of the coils until you are certain which wires are which.

Then place a normal high intensity LED across one winding (for example, in Fig.3 between terminals 1 and 2) and turn the stepper by hand. A good stepper motor will light the LED brightly, even with a slow shaft speed. (No, you don't need a rectifier – the LED will still light on the AC voltage.)

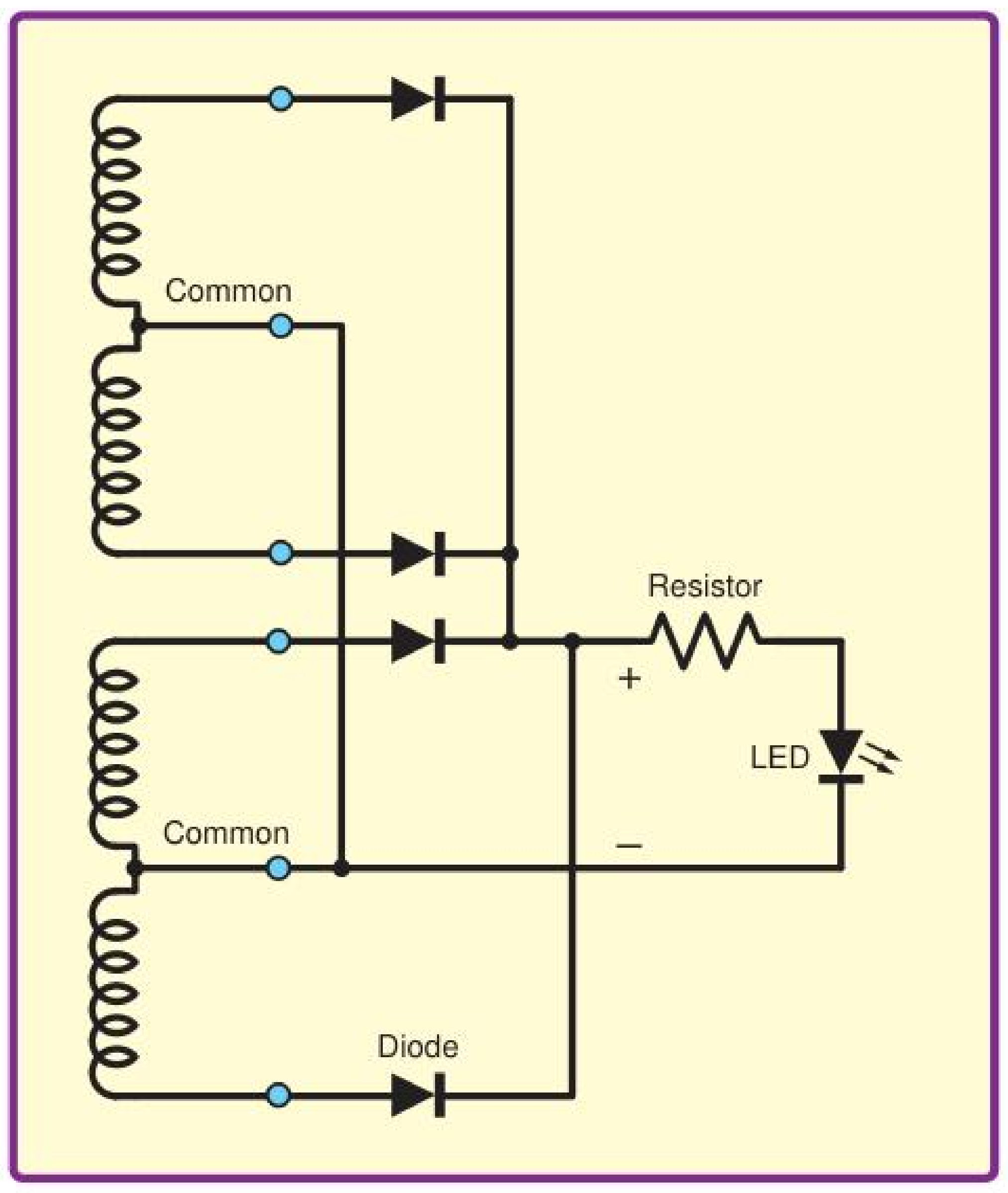


Fig.4. This is the set-up to test the suitability of the stepper motor as a hand-cranked torch alternator. The four diodes can be 1N4004 or similar. Select an LED dropping-resistor value that is sufficiently high that the LED cannot be overloaded with quick turns of the stepper motor shaft.

Next, short those two wires together. The stepper you want will be now much harder to turn, with a distinct gritty 'cogging' action. Then measure the DC resistance across the same two wires. The stepper that's best suited will have the lowest winding resistance – eg, less than 5Ω.

After all of that, do a final check. Connect four 1N4004 diodes to the output windings (see Fig.4) and see if the chosen LED illuminates brightly as the stepper motor (now an alternator) is turned. By this stage, you will need to be using a suitable dropping resistor with the LED.

In the final design (Fig.5), the rectified stepper motor output is connected

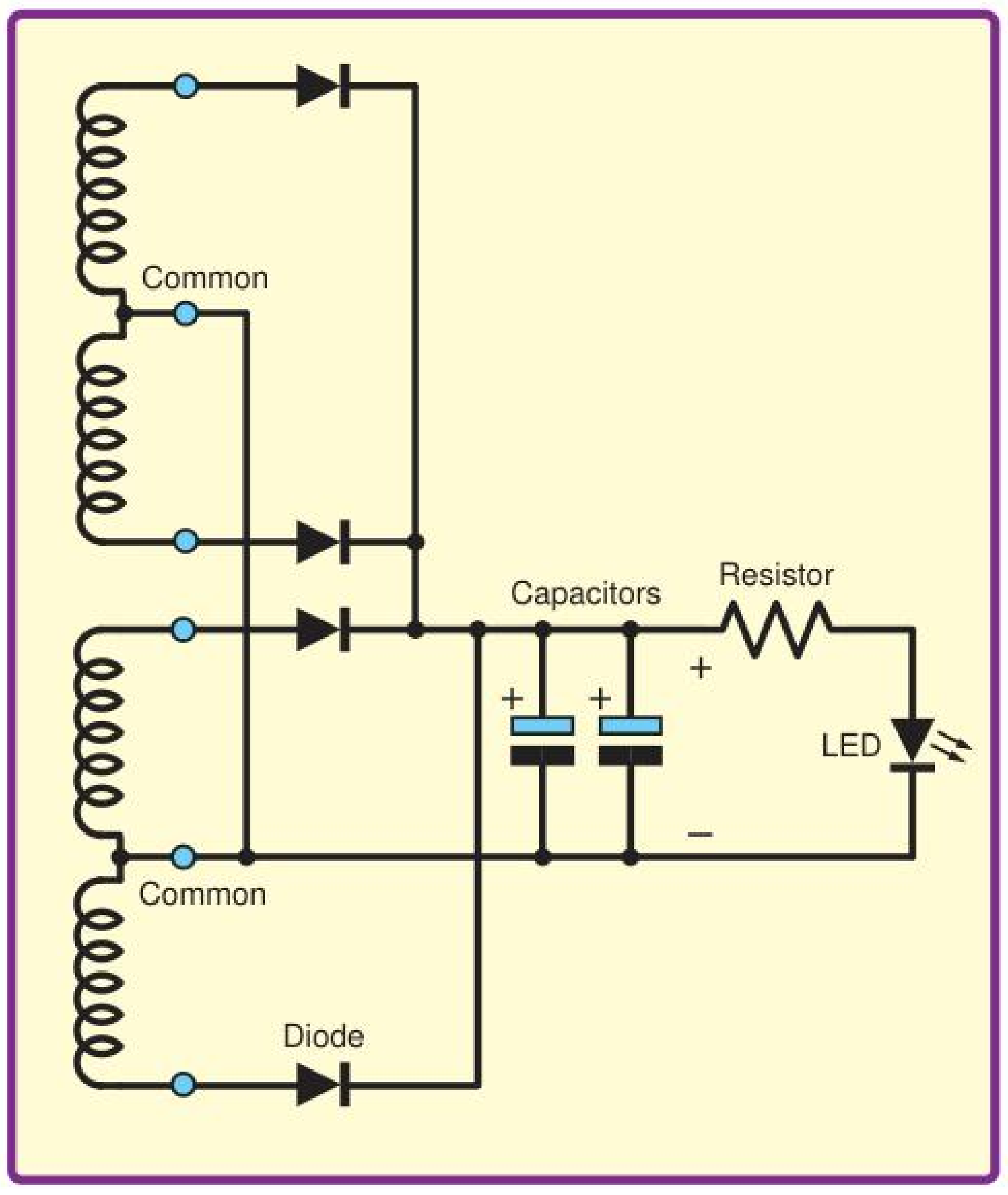


Fig.5. The capacitor bank stores the energy – two capacitors are shown here, but more can be used. The capacitors prevent the LED brightening and dimming as the knob is turned and allow the LED to stay on after the torch is no longer being cranked.

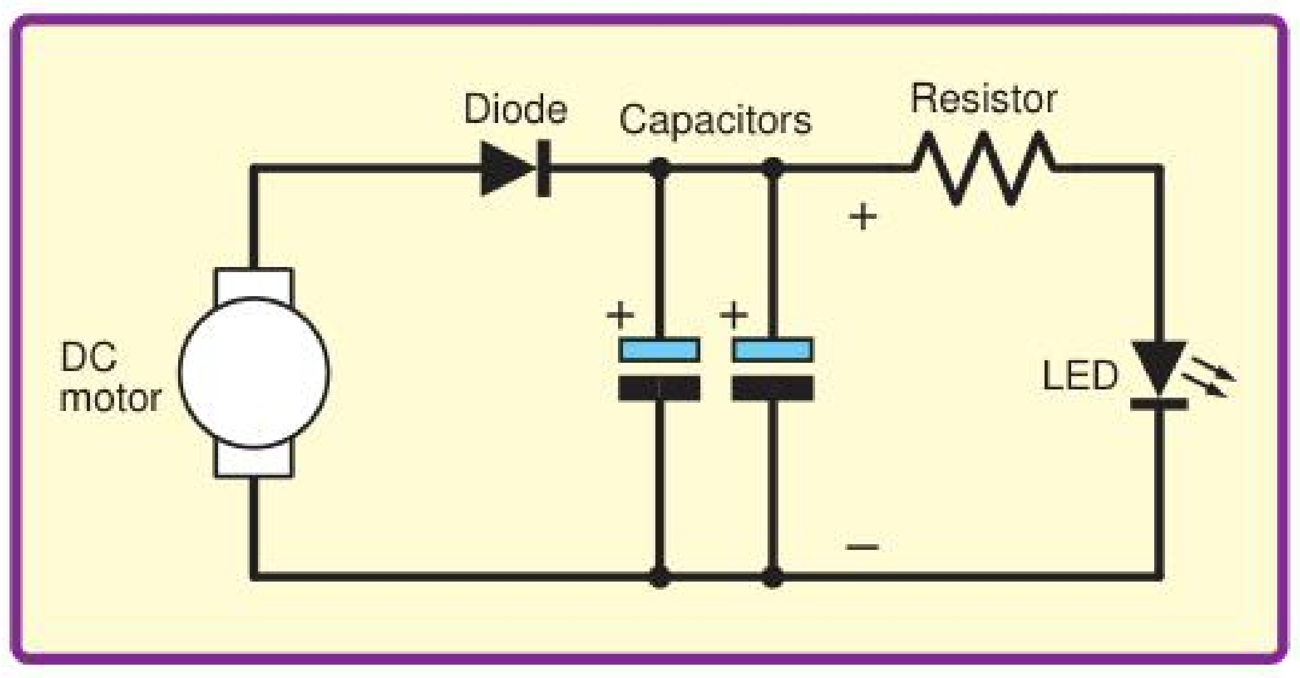


Fig.6. This approach uses a DC motor and gearbox, with the motor becoming a generator. The diode prevents the capacitor pack from discharging back through the motor's windings.

across the capacitor bank, and the capacitor bank drives the LED. Obviously, the polarity is important for both the LED and capacitors!

DC motor with integral gearbox

There are lots of small DC motors with integral gearboxes around – they're often used in toys, for example. However, when driven backwards (that is, the output shaft turned manually), many show themselves to be poor designs. Often they're noisy and require an uneven turning force as the gearbox housing distorts and so the mesh of the gears alters. But a high quality DC motor with a planetary gearbox placed at one end can work really well in a hand-cranked torch.

The disadvantage of taking this approach over a stepper motor is that the motor and gearbox are typically noisier, and even if a high quality design is used, it won't have the near unlimited life of the direct-drive stepper motor. However, the advantage is that you will be able to often get more power out of a smaller package.

As with the stepper motor, test the chosen unit by driving an LED. Use a single diode (eg, 1N4004) on the motor's output – later, this diode will stop the capacitor bank discharging back through the motor's windings. Start by using a high-value LED dropping resistor, and then reduce it until quick turning of the shaft does not overload the LED.

In the final design, shown in Fig.6, the generator's output is fed to the capacitor bank via the diode, and the capacitor bank drives the LED. Fig.7 shows just how compact a small DC motor torch can be.

Microwave oven turntable motor plus gearbox

This approach is a high voltage power source ***– be careful!***

Here, the power source is a salvaged turntable motor from a microwave oven, such as the one shown in Fig.8. (These can also be bought new very cheaply.)

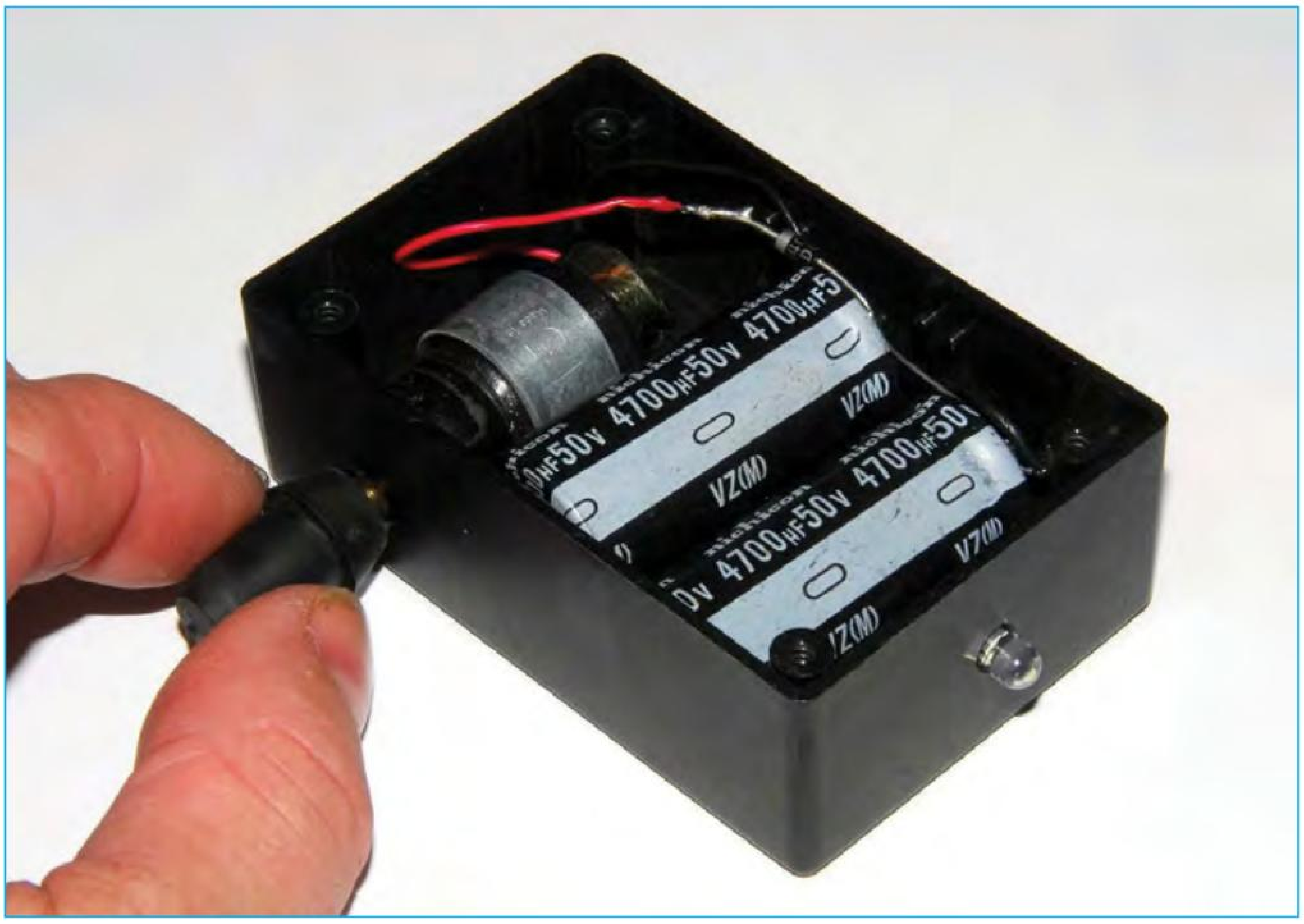


Fig.7. This is the view inside a torch that uses a small DC motor with integral planetary gearbox. Drive is via rubber knob. Result is a small and light torch (only 85 × 55 × 30mm and 110 grams) ideal as a bedside torch.

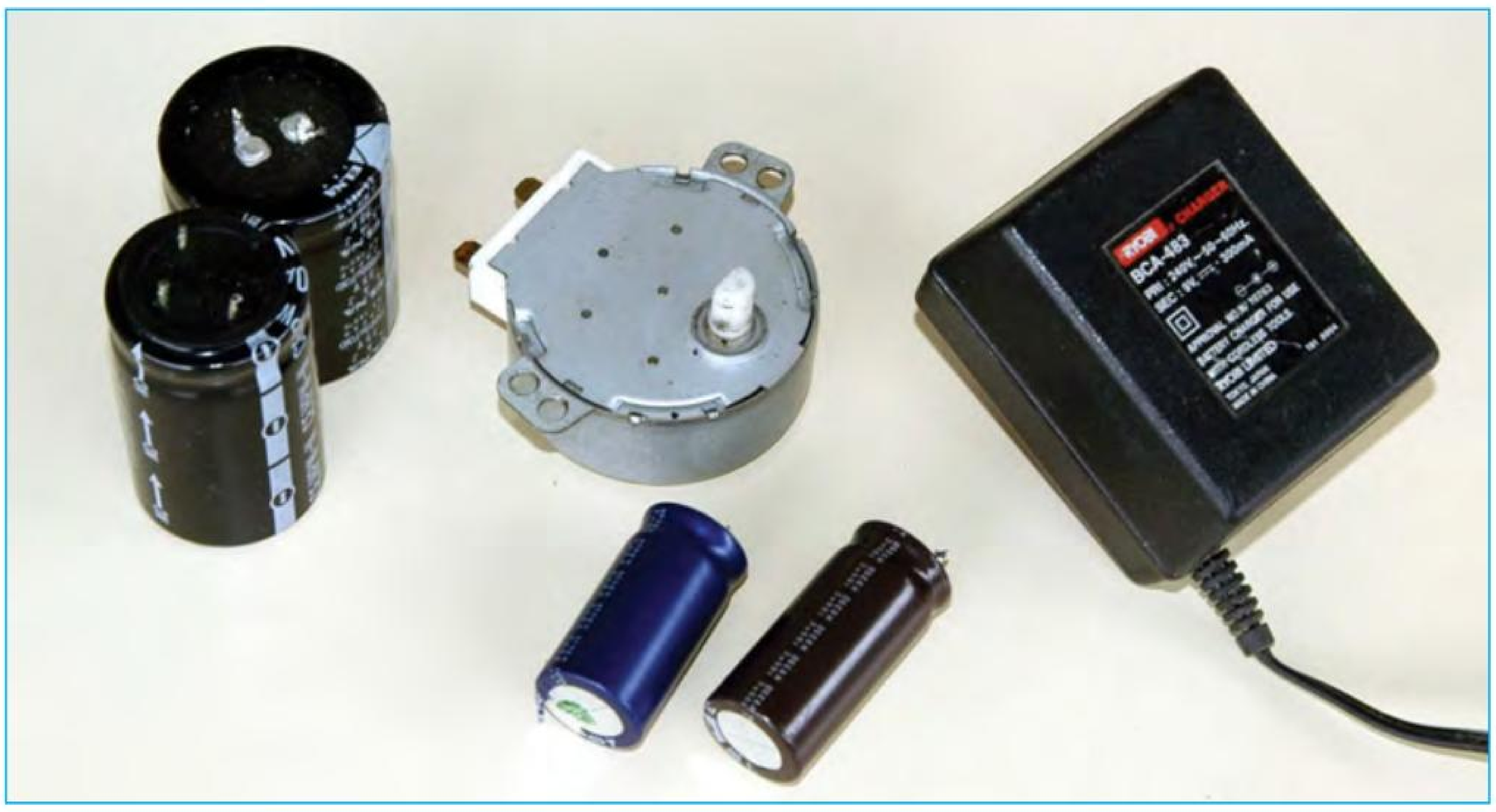


Fig.8. The main components for a torch that uses a microwave oven turntable motor as the high voltage power source. Shown here are the energy storage capacitors, the microwave oven motor and the plugpack from which the transformer and rectifying diodes are taken.

Turntable motors are AC synchronous designs that are about 20mm high and 50mm in diameter. In addition to the motor, inside the package is a system of plastic reduction gears that normally gives an output shaft speed of only about 5 RPM. But by turning the shaft with a knob, it's possible to easily generate up to several hundred volts AC output – the motor has become a high voltage alternator.

The disadvantage of taking this approach is that a large, strong knob will be needed – the shaft is quite stiff to turn. Operated in this way, the gear train is also quite noisy. Finally, you need to turn the knob fairly gently – turn it fast and you can strip the plastic gears. The advantage is that this approach gives more output power than anything else in a similar sized package, and so just a few winds of the knob can give enough power to keep the LED lit for many minutes.

Stepping down the high voltage produced by the alternator is a transformer,

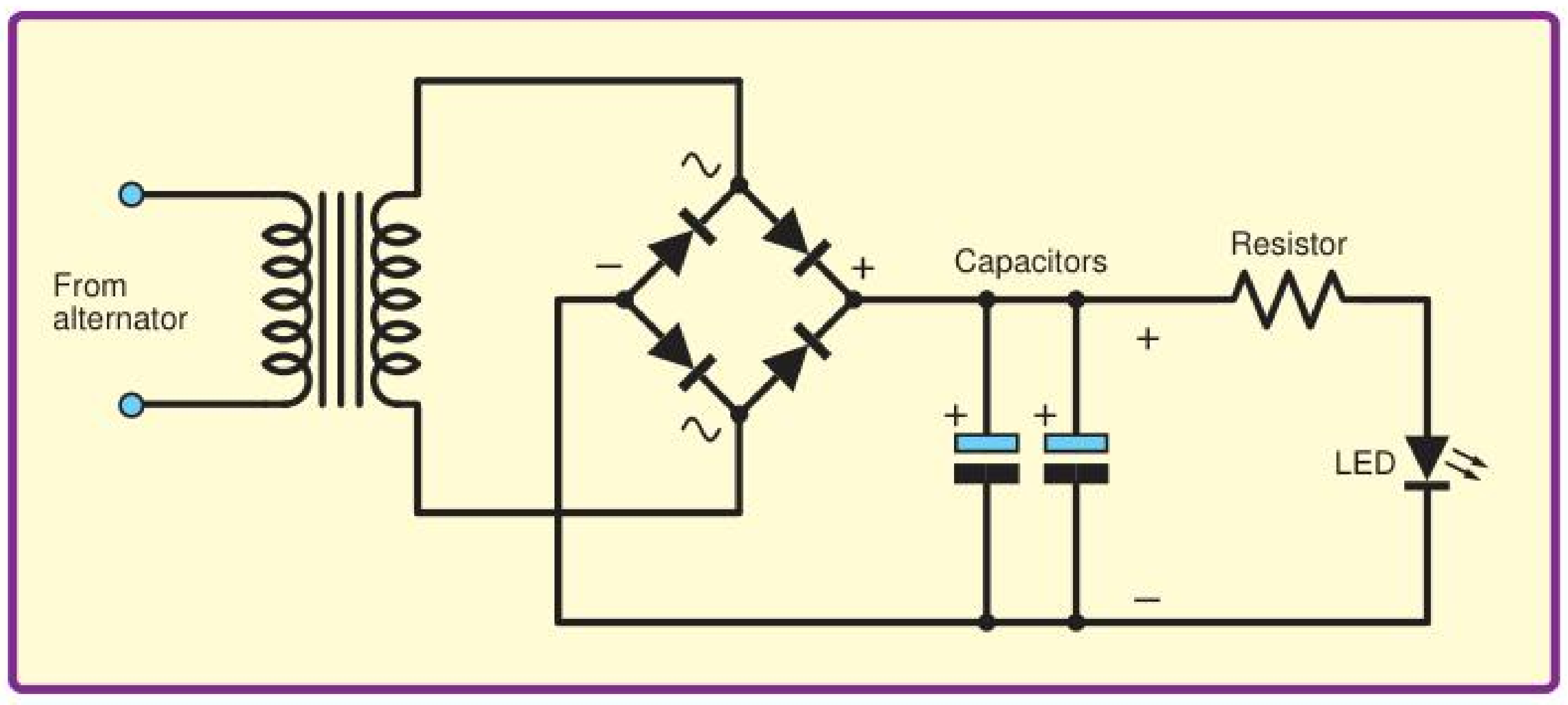


Fig.9. This design uses a microwave oven turntable motor driven backwards as a high voltage alternator. A transformer and bridge rectifier (taken from a small mains plugpack) reduces the voltage and then turns it into DC suitable for the capacitor pack and LED.

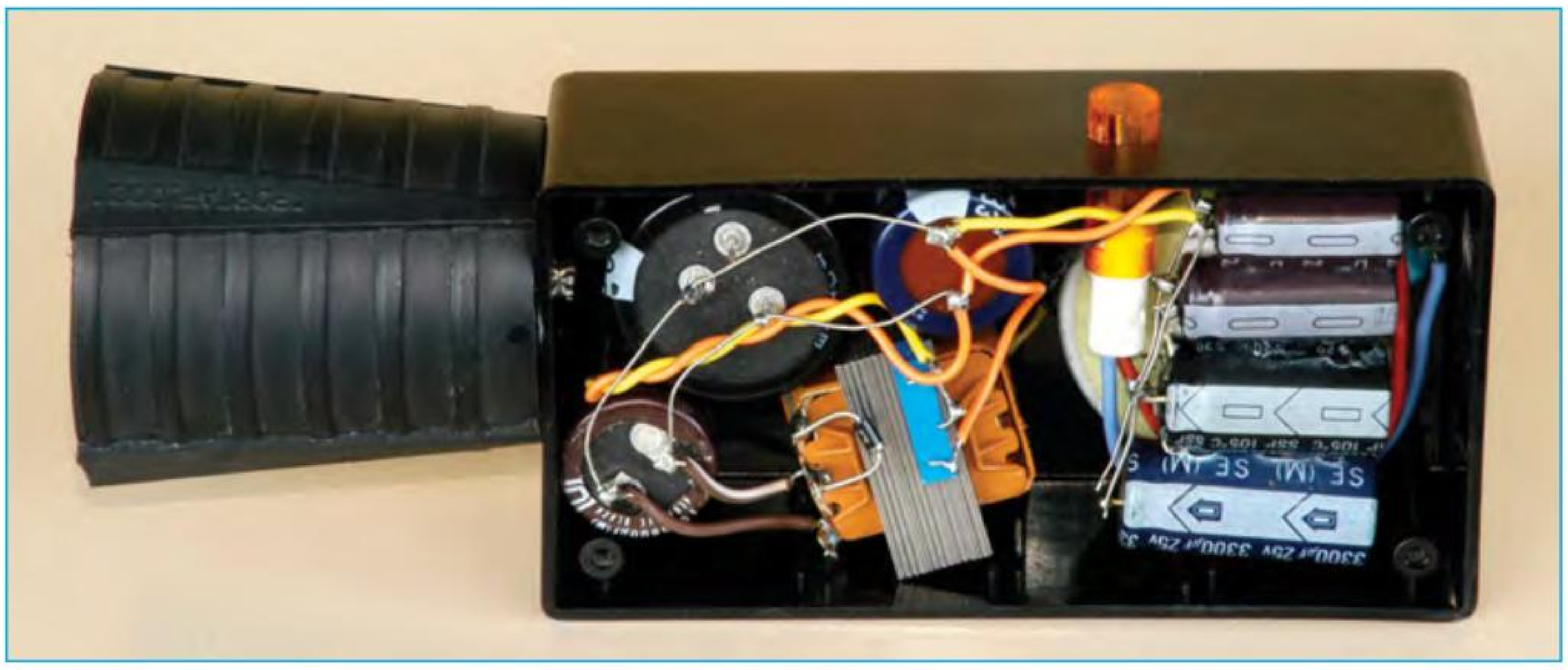


Fig.10. Inside the torch that uses the microwave oven motor. This design uses focused optics (a camera lens front element is placed in the conical extension at left) and a neon pilot lights that illuminates with the high voltage that occurs when the knob is being turned.

and then rectification of the AC occurs with diodes (or a bridge rectifier). These components are easily sourced from a discarded, transformer-type mains plugpack.

To see if the plugpack is suitable, do some initial testing. Connect the plugpack mains input terminals to the alternator outputs. Then connect the output of the plugpack to the capacitor pack, observing the correct polarity. Connect your multimeter across the capacitor pack. Turn the knob and you should be able to read a voltage that rises as you keep on turning. Any voltage from about 6V to 12V is fine. (Note that when you need to remove the plugpack's innards to build them into the box, open the plugpack by crushing the case slowly in a bench vice until it loudly cracks.)

Then it is simply a case of building all the components into a suitable enclosure. However, note that unlike the other approaches, the box must protect against high voltages – including if the torch becomes damp.

For the final design, see Fig.9, the rectified alternator's output is fed to the capacitor bank, and the capacitor bank drives the LED. Fig.10 shows the components packed into a plastic (ie, insulating) case.

Cranking the torch

The approach that you take to turning the generator is up to you – but I prefer knobs over levers.

In stepper motor powered designs, the shaft can be rotated in either direction to light the torch. Attaching a knob directly to the shaft and using a quick back and forth rotation works well.

In DC motor designs, the shaft can be rotated only one way. In these cases, a short lever with a knob placed on its end works well. However, again, I often just choose to place a knob directly on the shaft.

In microwave oven motor designs, the required turning force is high and the input shaft must not be rotated too quickly or else gears will be stripped – definitely use a large knob.

Conclusion

Making torches like these is great fun and you end up with a very practical device. Plus, you're not limited to just the designs covered here. For example, you can also add optics to improve the LED's reach – an ex-35mm film SLR camera lens makes a great starting point. On the 'microwave oven' design, you can add a neon that lights with the high voltage cranking.

You can also make torches of very different sizes. My largest hand-cranked torch uses a huge ex-photocopier geared stepper motor, turned with a long handle. It will drive a 5W LED and equipped with ex-camera optics will light up objects 100 metres away. My smallest torch uses a DC gear-train motor, weighs just 110 grams and is all housed in a box only 85 × 55 × 30mm. *Have a go!*

Next month

Here's a small, but very smart *LED Battery Monitor*. It may look like an ordinary LED but packed inside is a 6V, 12V and 24V battery monitor. The tricolour 'traffic light' LED can be programmed to flash all kinds of messages depending on the state of your battery. All this is in our next super *Electronic Building Block* article.

Next month – compact LED Battery Monitor

What about a switch?

I don't bother fitting a switch. When you want to use the torch, just give the knob or lever a few turns. When you've finish using the torch, just put it down! Depending on the chosen capacitors, type of LED and how much power you've generated, the LED may stay visible for literally hours. However, even as a bedside torch, after a few minutes it will have dimmed sufficiently not to be distracting.

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PCB SERVICE

CHECK US OUT ON THE WEB

Basic printed circuit boards for most recent *EPE* constructional projects are available from the *PCB Service*, see list. These are fabricated in glass fibre, and are drilled and roller tinned, but all holes are a standard size. They are not silk-screened, nor do they have solder resist. Double-sided boards are **NOT plated through hole** and will require 'vias' and some components soldering to both sides. **NOTE: PCBs from the July 2013 issue with eight digit codes** have silk screen overlays and, where applicable, are double-sided, plated through-hole, with solder masks, they are similar to the photos in the relevent project articles.

All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

NOTE: While 95% of our boards are held in stock and are dispatched within seven days of receipt of order, please allow a maximum of 28 days for delivery – overseas readers allow extra if ordered by surface mail.

Back numbers or photocopies of articles are available if required – see the Back Issues page for details. WE DO NOT SUPPLY KITS OR COMPONENTS FOR OUR PROJECTS.

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Boards can only be supplied on a payment with order basis.

EPE SOFTWARE

Where available, software programs for *EPE* Projects can be downloaded free from the Library on our website, accessible via our home page at:
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PCB masters for boards published from the March '06 issue onwards are available in PDF format free to subscribers – email **fay.kearn@wimborne.co.uk** stating which masters you would like**.**

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Next Month

Content may be subject to change

Low-cost, Accurate Voltage/Current/Resistance Reference

Here's a handy small module based on a lithium coin cell, a voltage reference IC, a precision resistor and little else. It can be used for checking or calibrating multimeters or anywhere that an accurate and stable voltage is required. Plus, we'll provide details for using the Reference with Arduino and a supporting article on checking your multimeter.

USB Power Monitor

Curious about how much power your USB peripherals use? Perhaps you are building a USB device and want to check its consumption. Or maybe you want to figure out how many devices you can plug into an un-powered hub or what impact a USB device has on your laptop battery life. Build this *USB Power Monitor* and find out.

Driveway Monitor – Part 2

Last month, we introduced our new *Driveway Monitor* and described how it worked. This month, we describe how to build, test and install it in your driveway. We also describe the various options so that you can build it to operate just the way you want.

Teach-In 2016 – Part 7

In next month's *Teach-In 2016 Arduino World* we will be looking at the Arduino Uno's diminutive cousin, the Arduino Nano. This tiny microcontroller provides you with a highly cost-effective alternative to the Uno that's small enough to be tucked away into an extremely small space. We'll also look at infrared motion sensors, tone generation techniques and the construction of a simple Arduino Nano-based PIR intruder detector.

PLUS!

All your favourite regular columns from *Audio Out* and *Circuit Surgery* to *Electronic Building Blocks, PIC n' Mix* and *Net Work.*

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Published on approximately the first Thursday of each month by Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Printed in England by Acorn Web Offset Ltd., Normanton, WF6 1TW. Distributed by Seymour, 86 Newman St., London W1T 3EX. Subscriptions INLAND: £23.50 (6 months); £43.00 (12 months); £79.50 (2 years). EUROPE: airmail service, £28.00 (6 months); £52.00 (12 months); £99.00 (2 years). REST OF THE WORLD: airmail service, £37.00 (6 months); £70.00 (12 months); £135.00 (2 years). Payments payable to "Everyday Practical Electronics", Subs Dept, Wimborne Publishing Ltd. Email: subs@epemag.wimborne.co.uk. EVERYDAY PRACTICAL ELECTRONICS is sold subject to the following conditions, namely that it shall not, without the written consent of the Publishers first having been given, be lent, resold, hired out or otherwise disposed of by way of Trade at more than the recommended selling price shown on the cover, and that it shall not be lent, resold, hired out or otherwise disposed of in a mutilated condition or in any unauthorised cover by way of Trade or affixed to or as part of any publication or advertising, literary or pictorial matter whatsoever.

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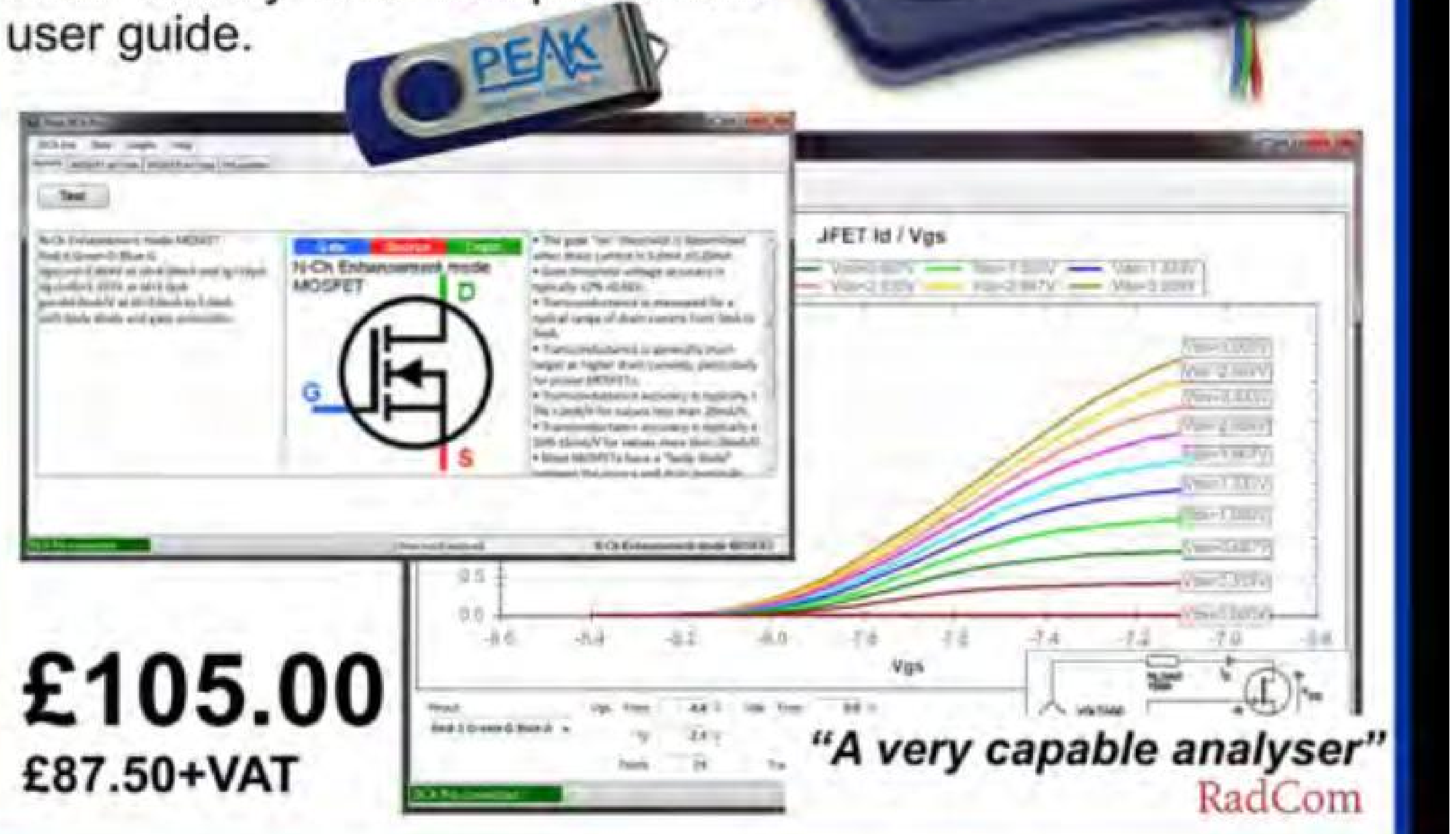
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